Figures

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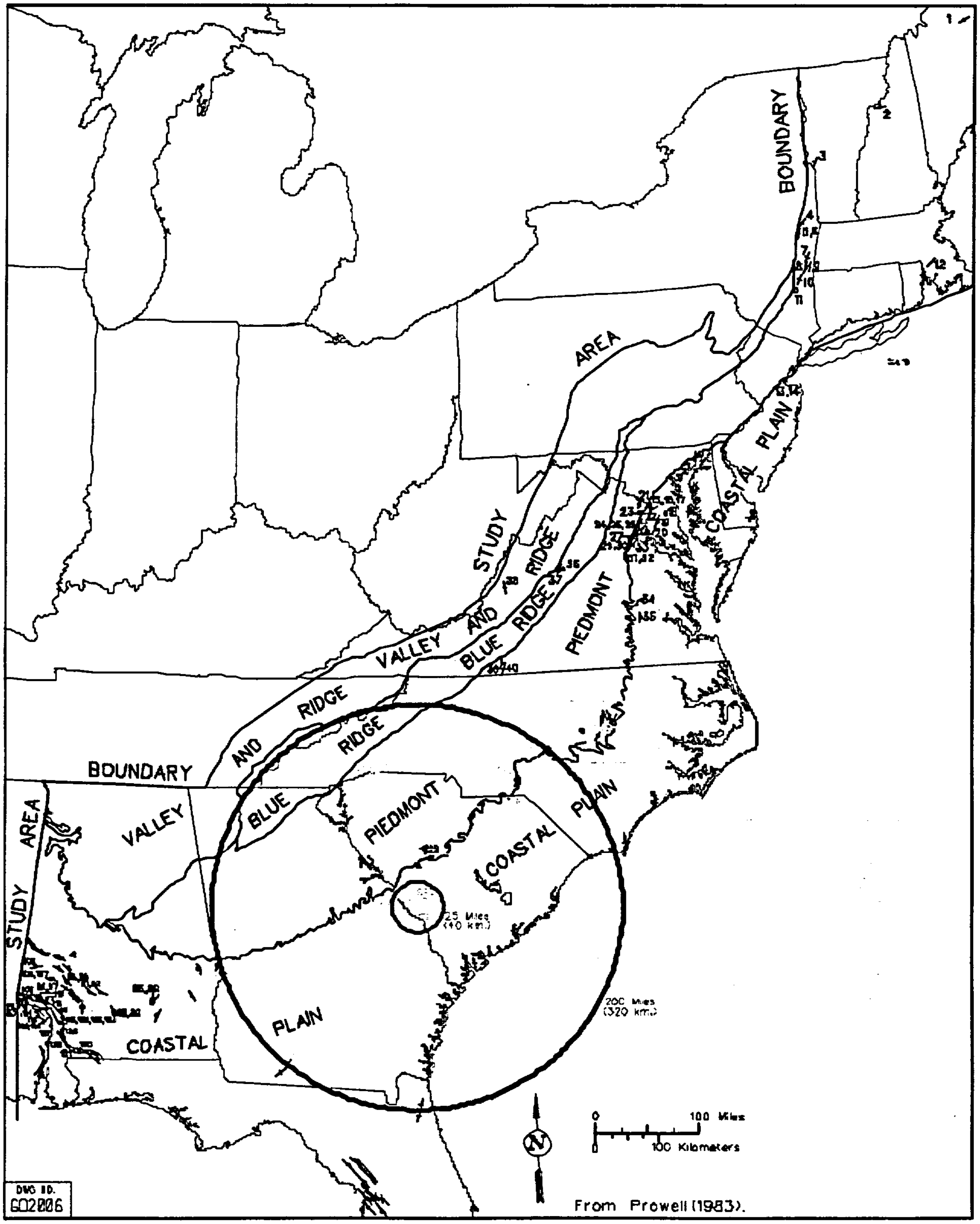

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Figure 1.3.5-1. Relationship of SRS to Regional Geological Provinces and Terranes

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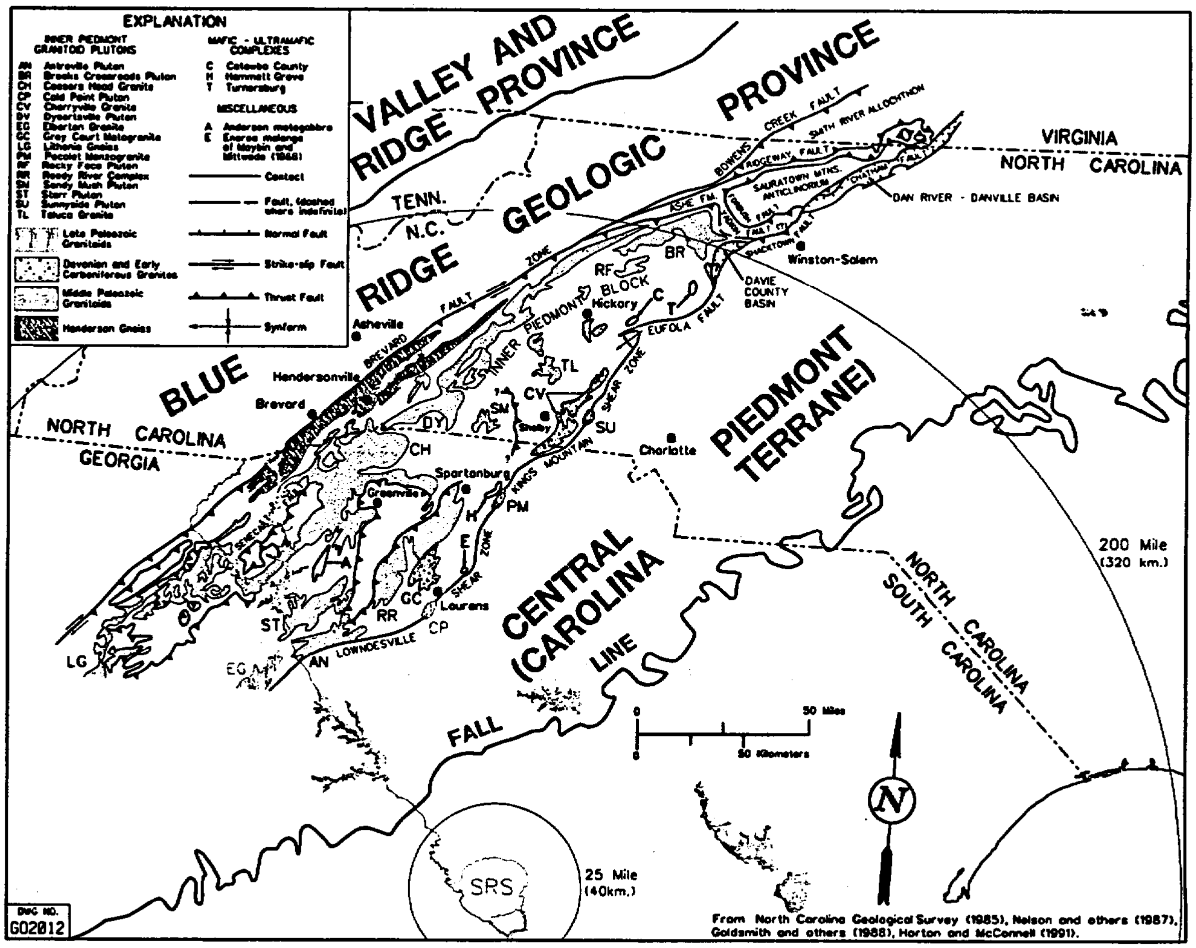

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Figure 1.3.5-2. Piedmont and Carolina Terrane

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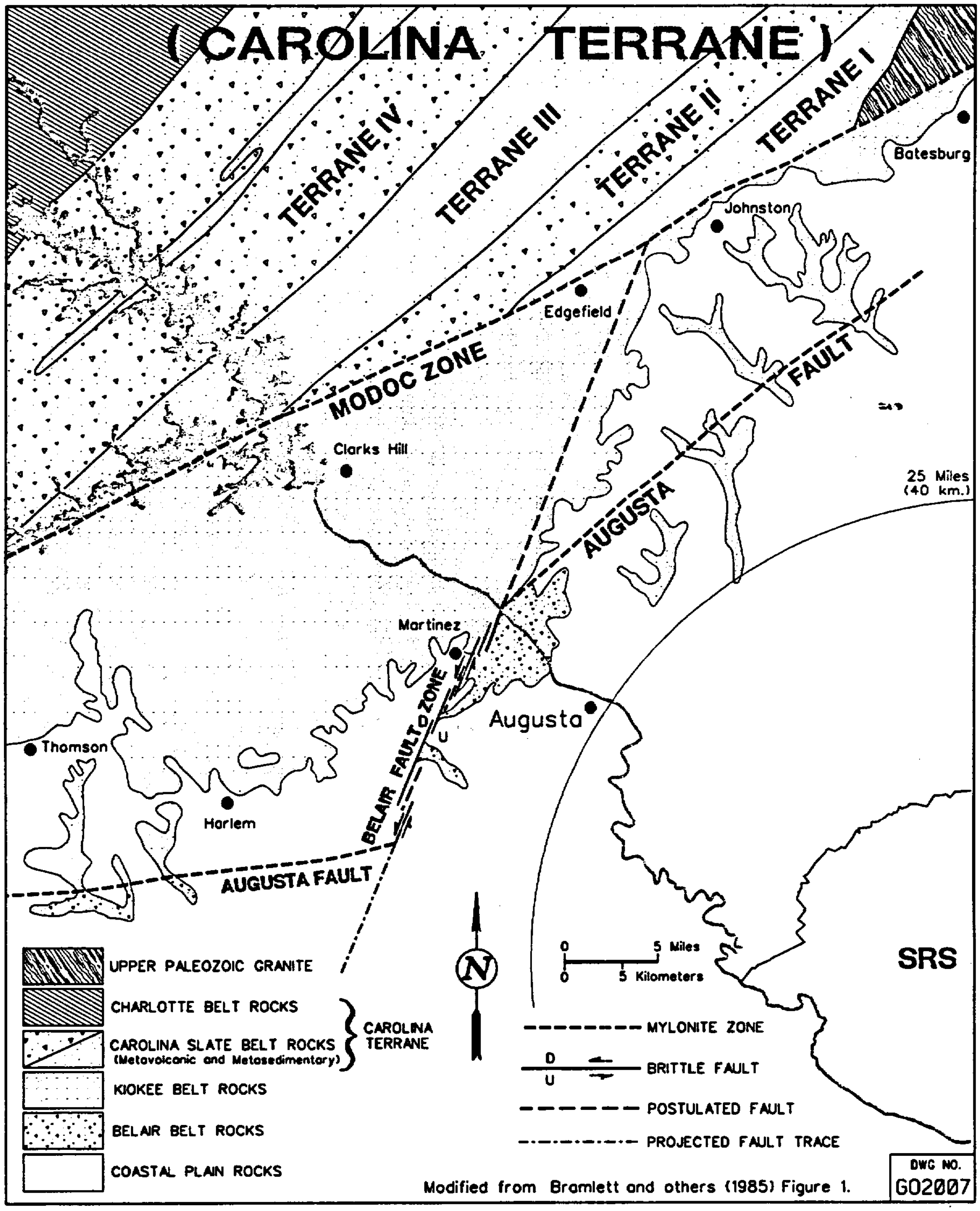

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Figure 1.3.5-3. Carolina Terrane

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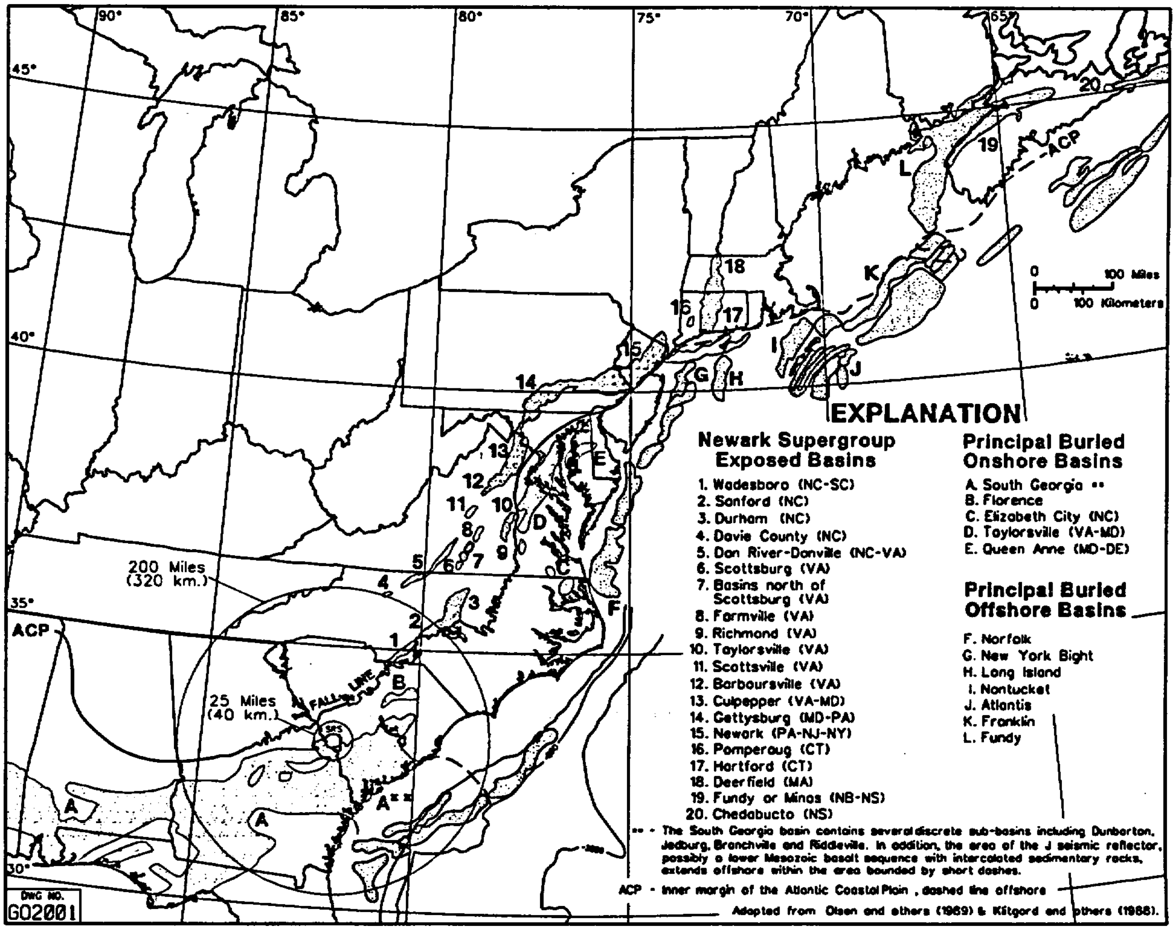

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Figure 1.3.5-4. Location of Mesozoic Rift Basins Along the Entire Eastern Continental Margin of North America From the Gulf Coast Through Nova Scotia

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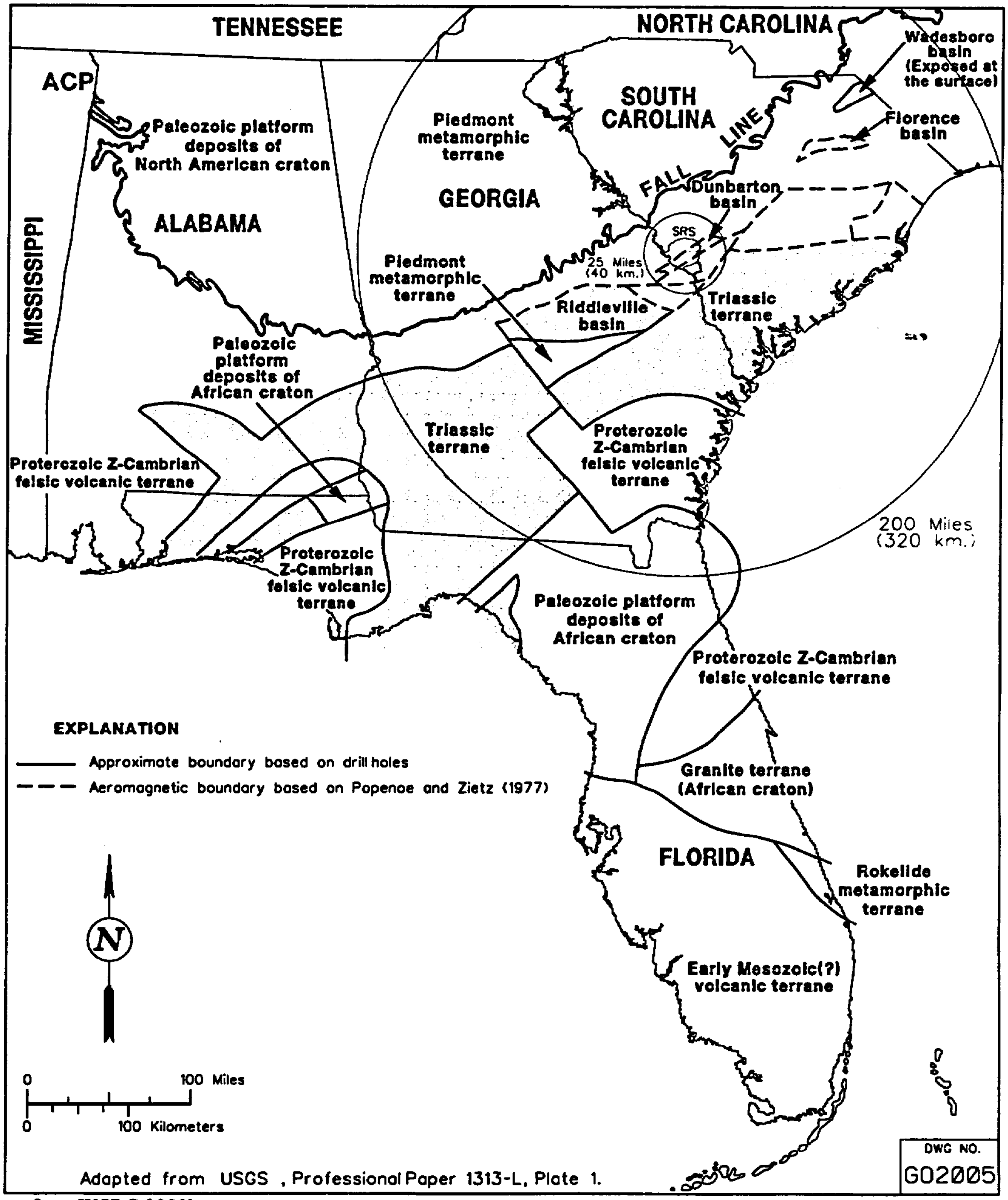

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Figure 1.3.5-5. The Triassic Basins Beneath the Alabama, Florida, Georgia, and South Carolina Coastal Plains

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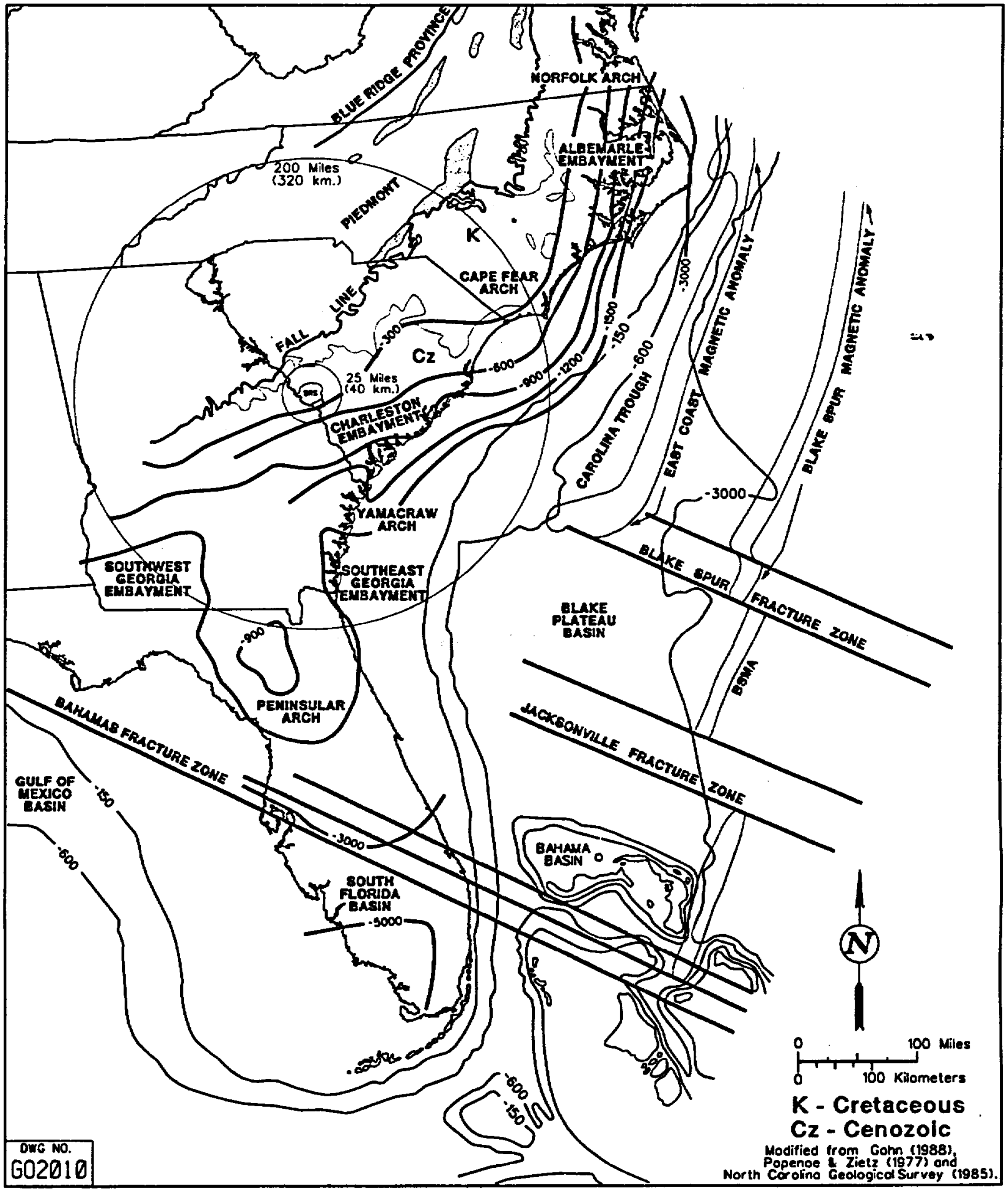

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Figure 1.3.5-6. Structural Configuration of the Atlantic Continental Margin

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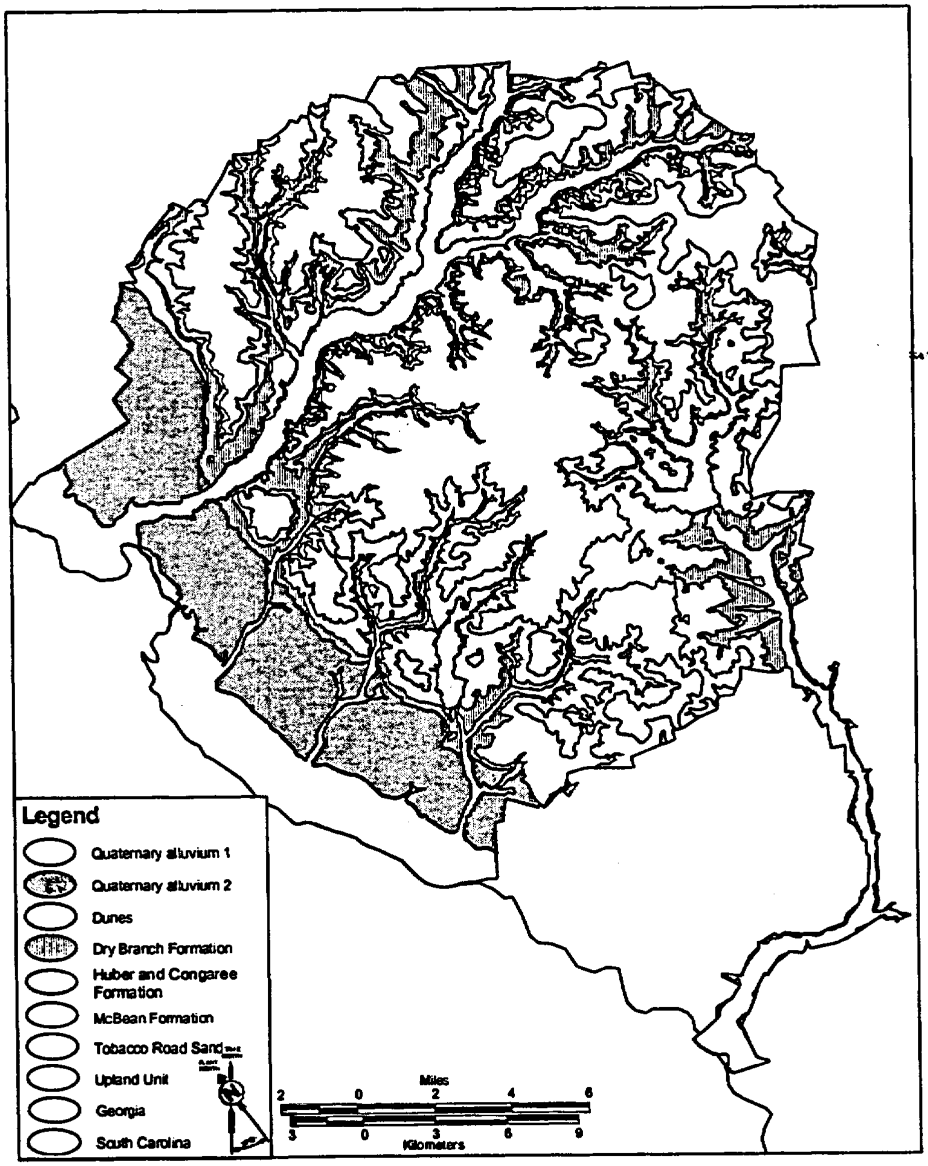

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Figure 1.3.5-7. Geologic Map of the Savannah River Site

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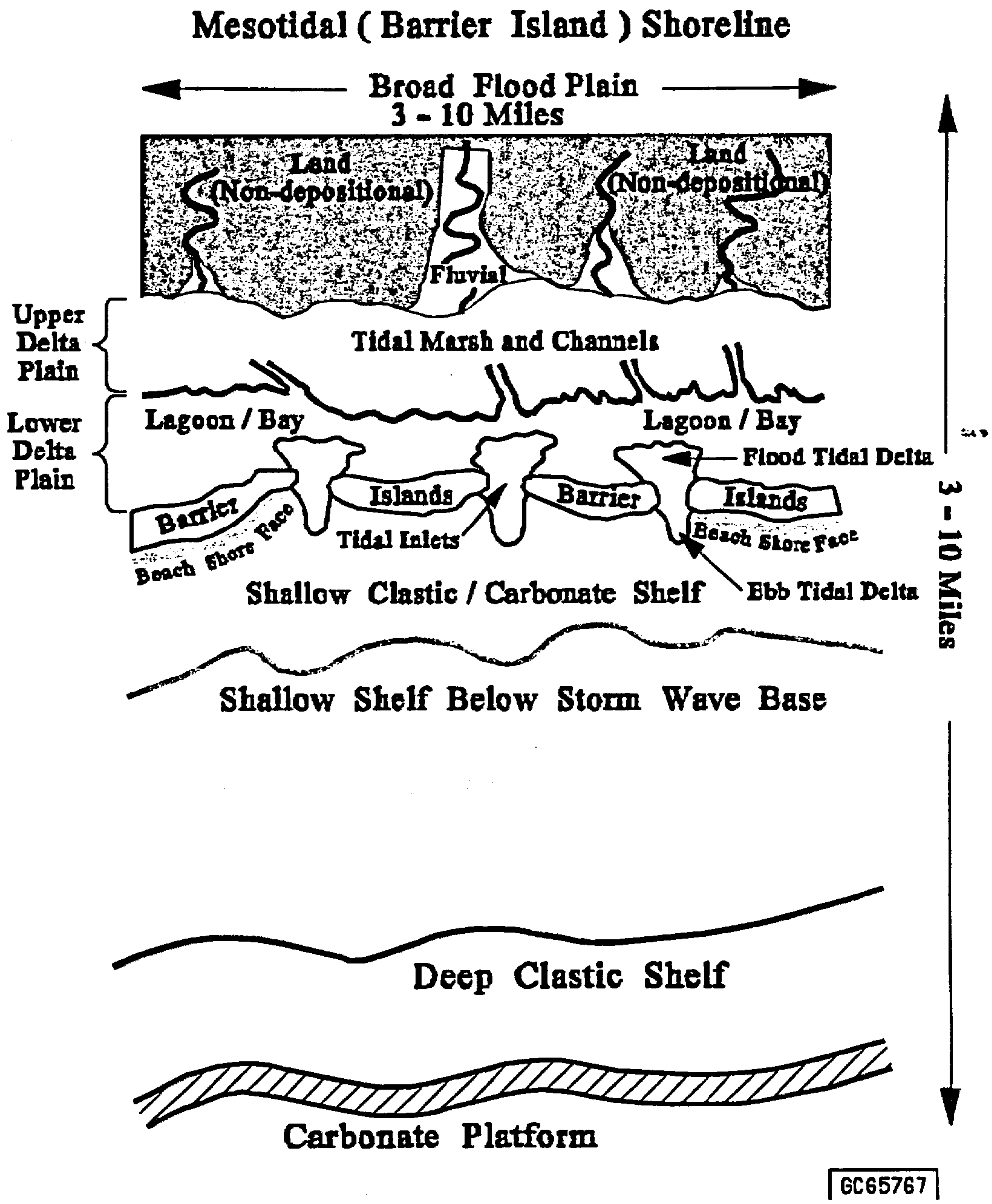

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Figure 1.3.5-8. Spatial Relationships of Repositional Environments Typical of the Tertiary Sediments at SRS

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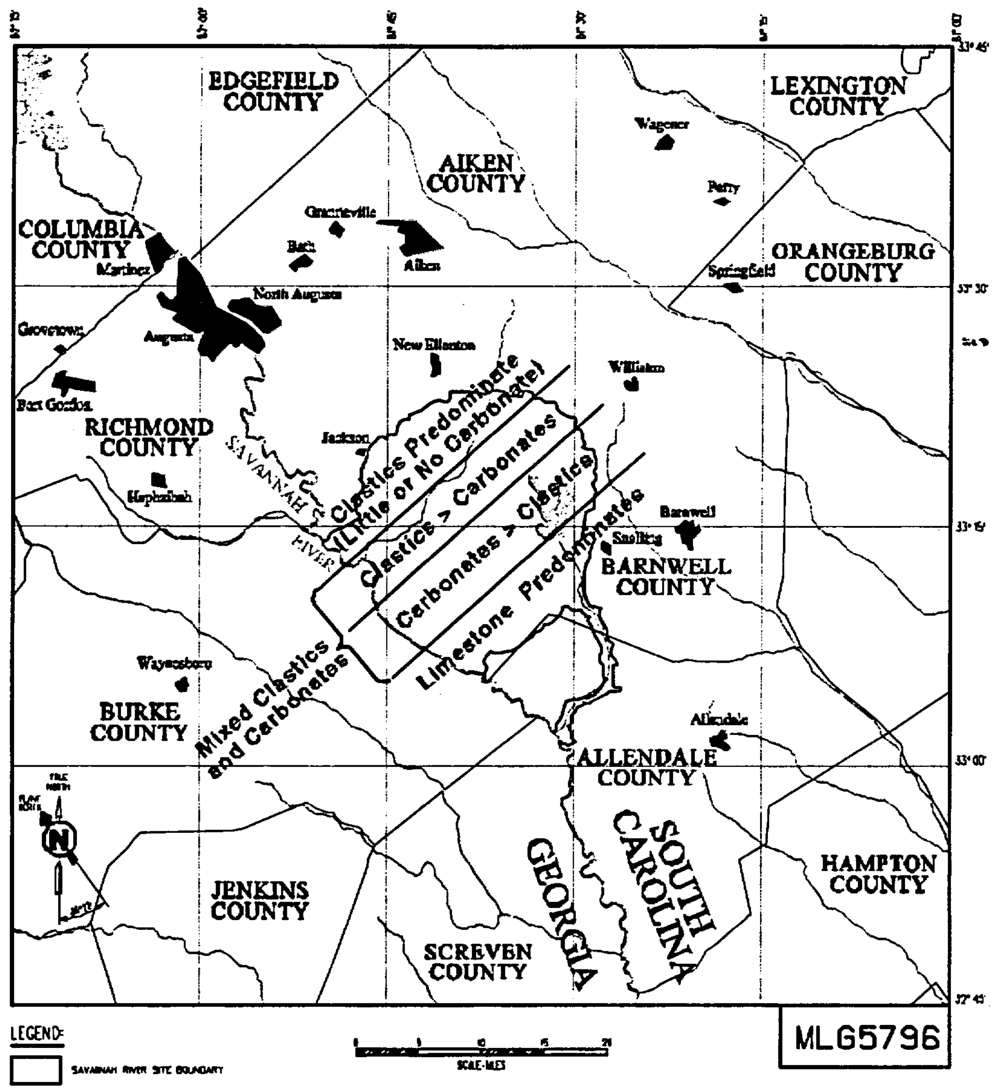

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Figure 1.3.5-9. Regional Distribution of Carbonate in the Santee/Utley-Dry Branch Sequence

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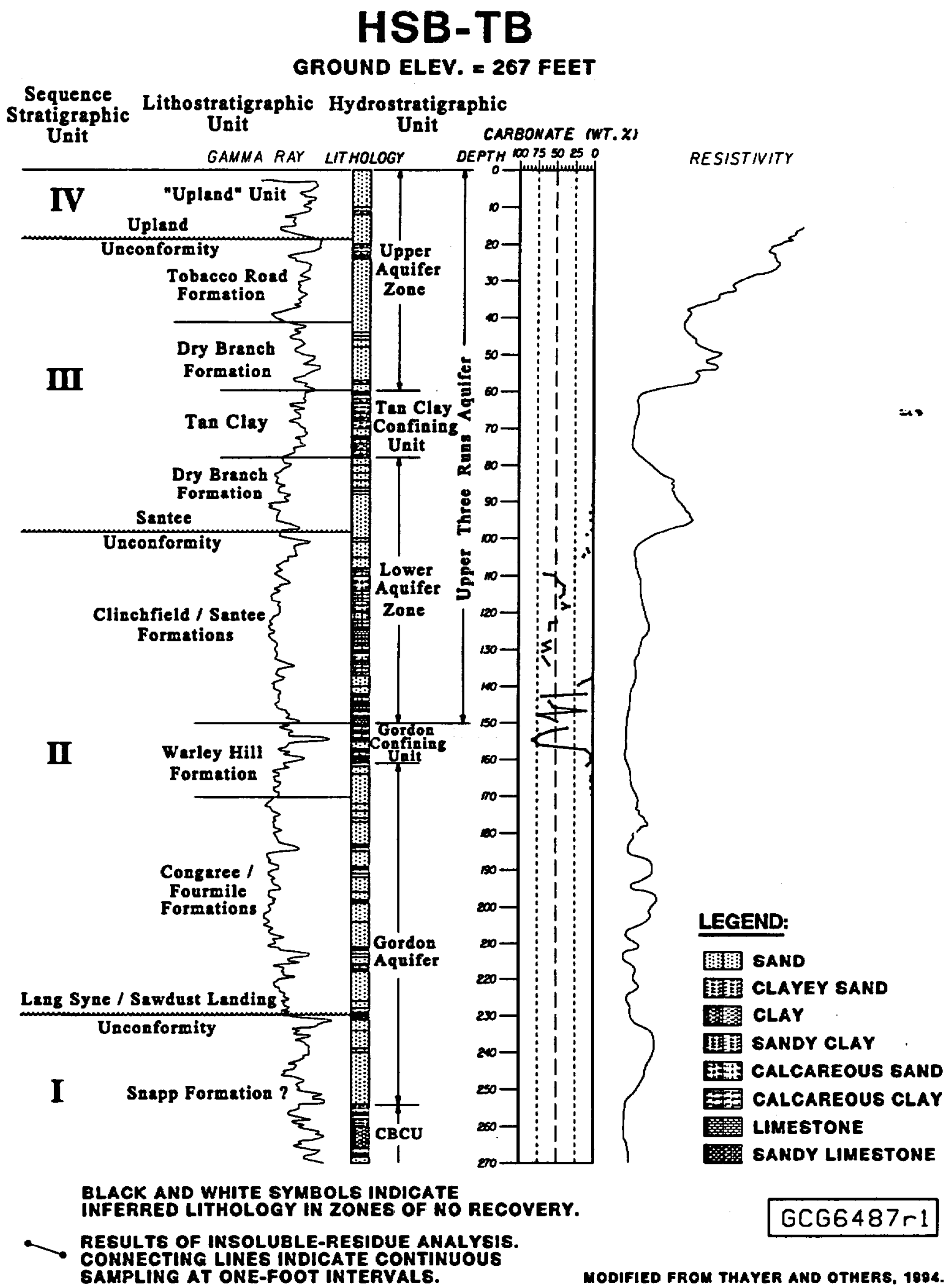

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Figure 1.3.5-10. Lithologic and Geophysical Signature Typical of the Tertiary Section of the General Separations Area, Savannah River Site

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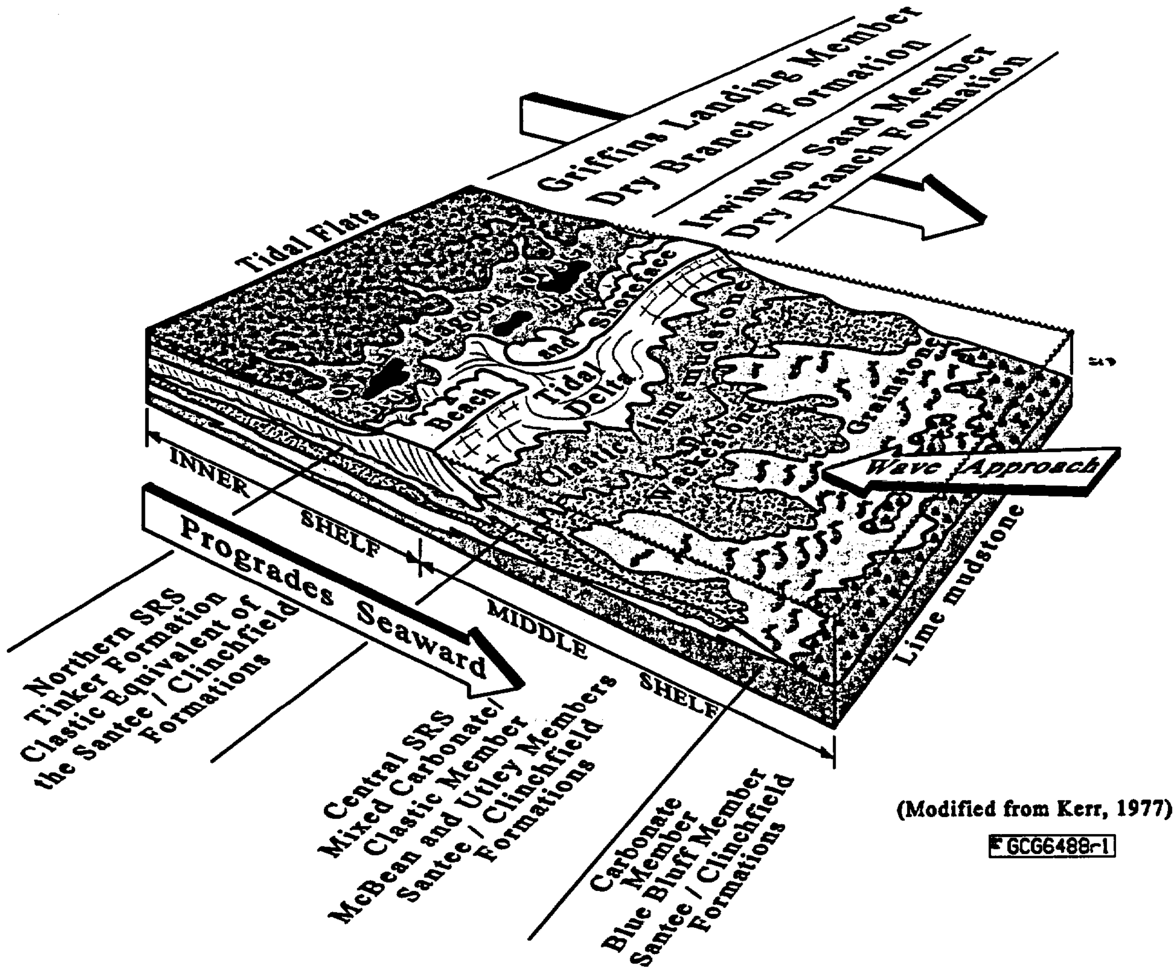

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Figure 1.3.5-11. Spatial Relationships of Depositional Environments Typical of the Dry Branch and Tinker/Santee (Utley) Sediments at SRS

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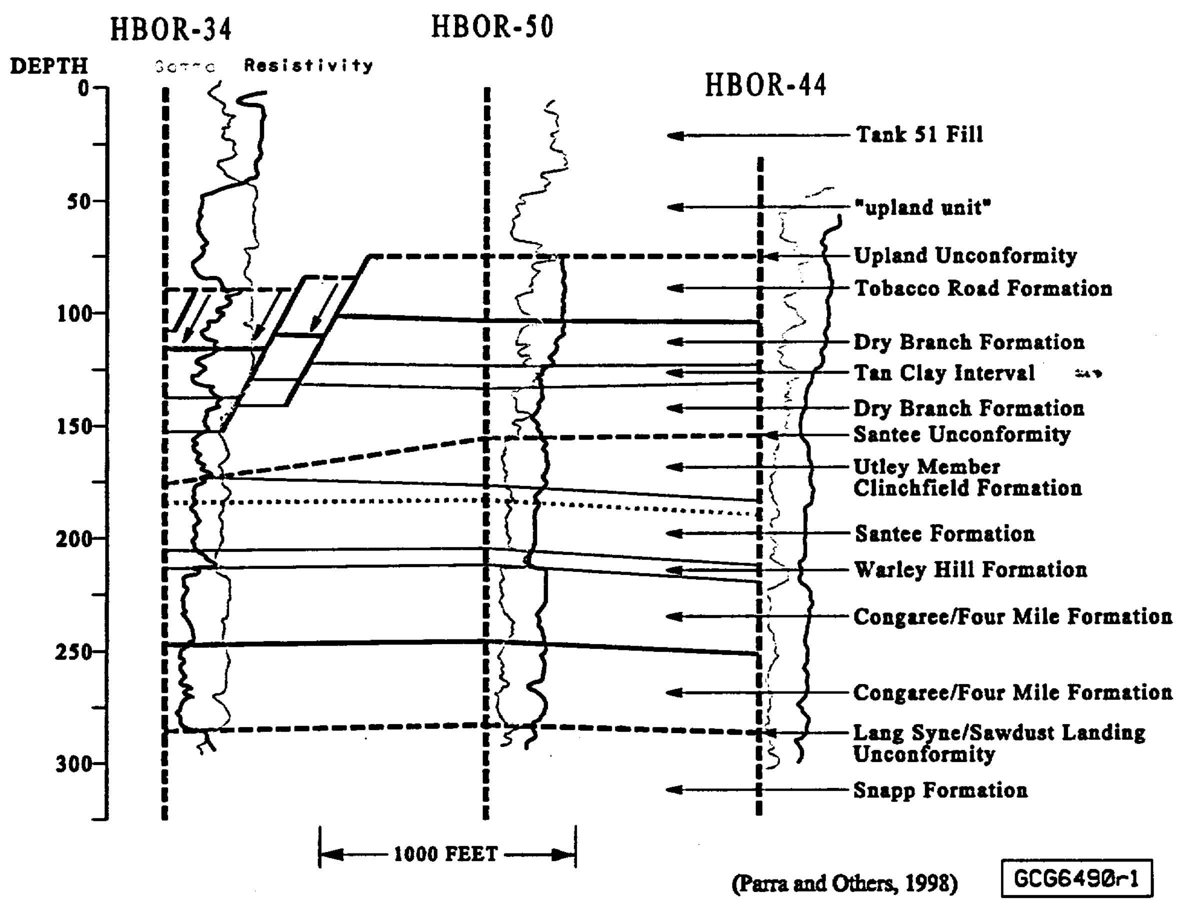

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Figure 1.3.5-12. Carbonate Dissolution in the Tinker/Santee (Utley) Interval Resulting in Consolidation and Slumping of the Overlying Sediments of the Tobacco Road and Dry Branch Formations into the Resulting Lows

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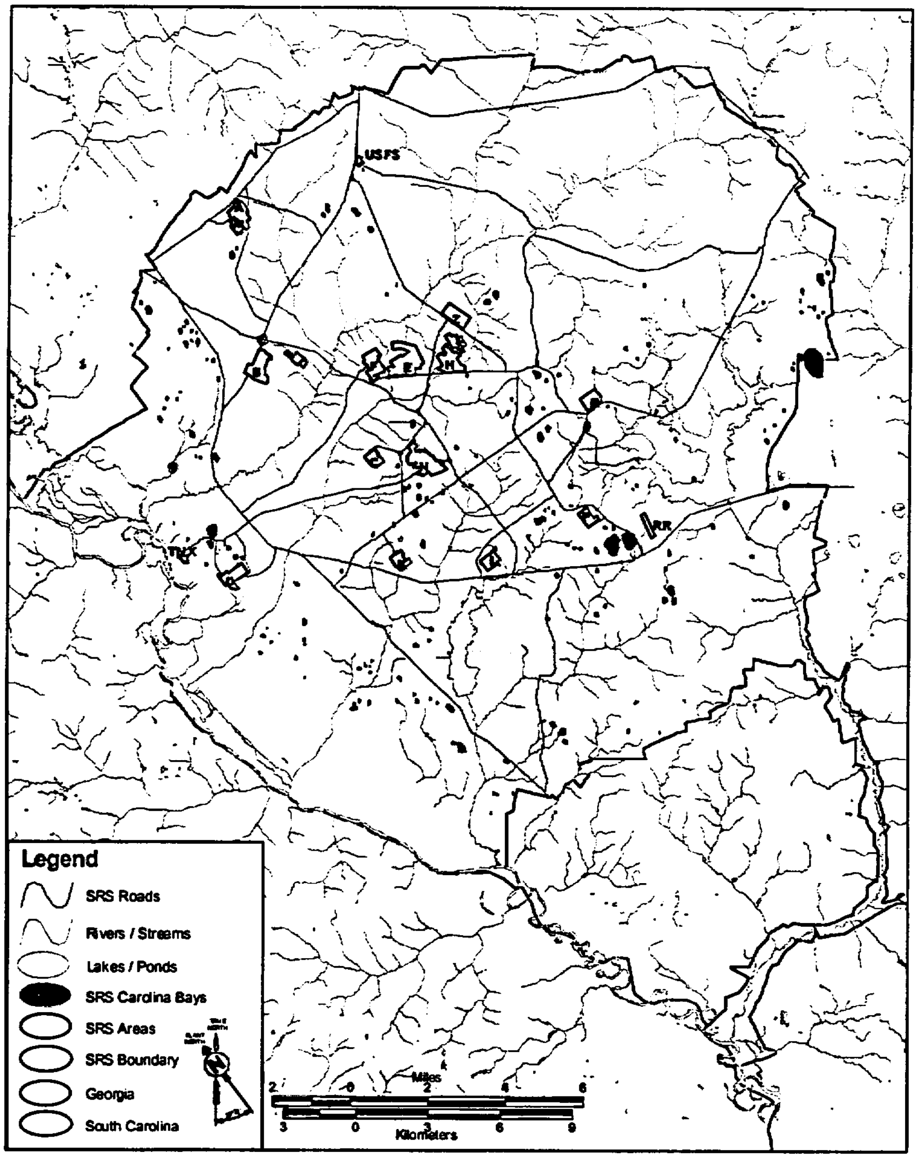

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Figure 1.3.5-13. Distribution of Carolina Bays Within the Savannah River Site

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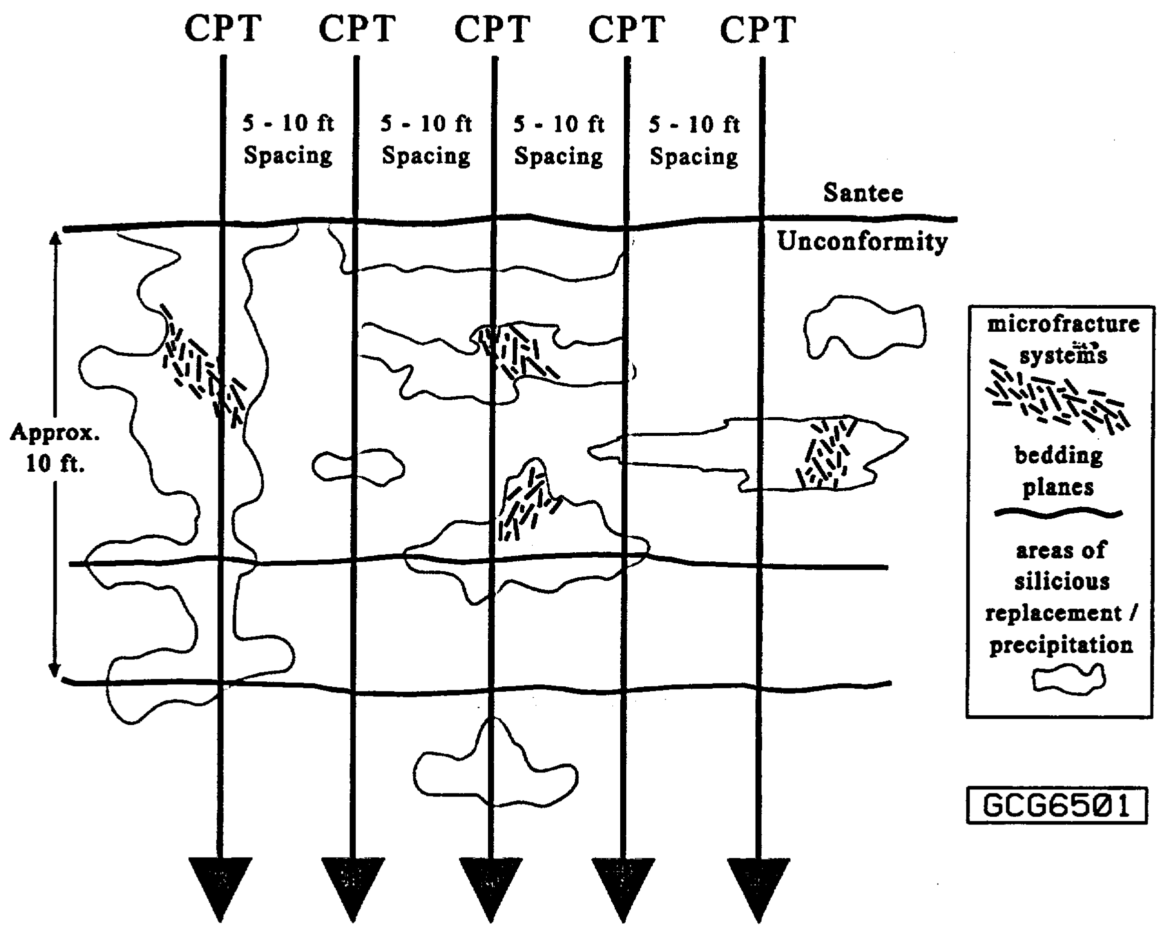

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Figure 1.3.5-14. Diagram Illustrating the Stratigraphic and Lateral Distribution of Soft Zones Due to Silica Replacement of Carbonate in the GSA

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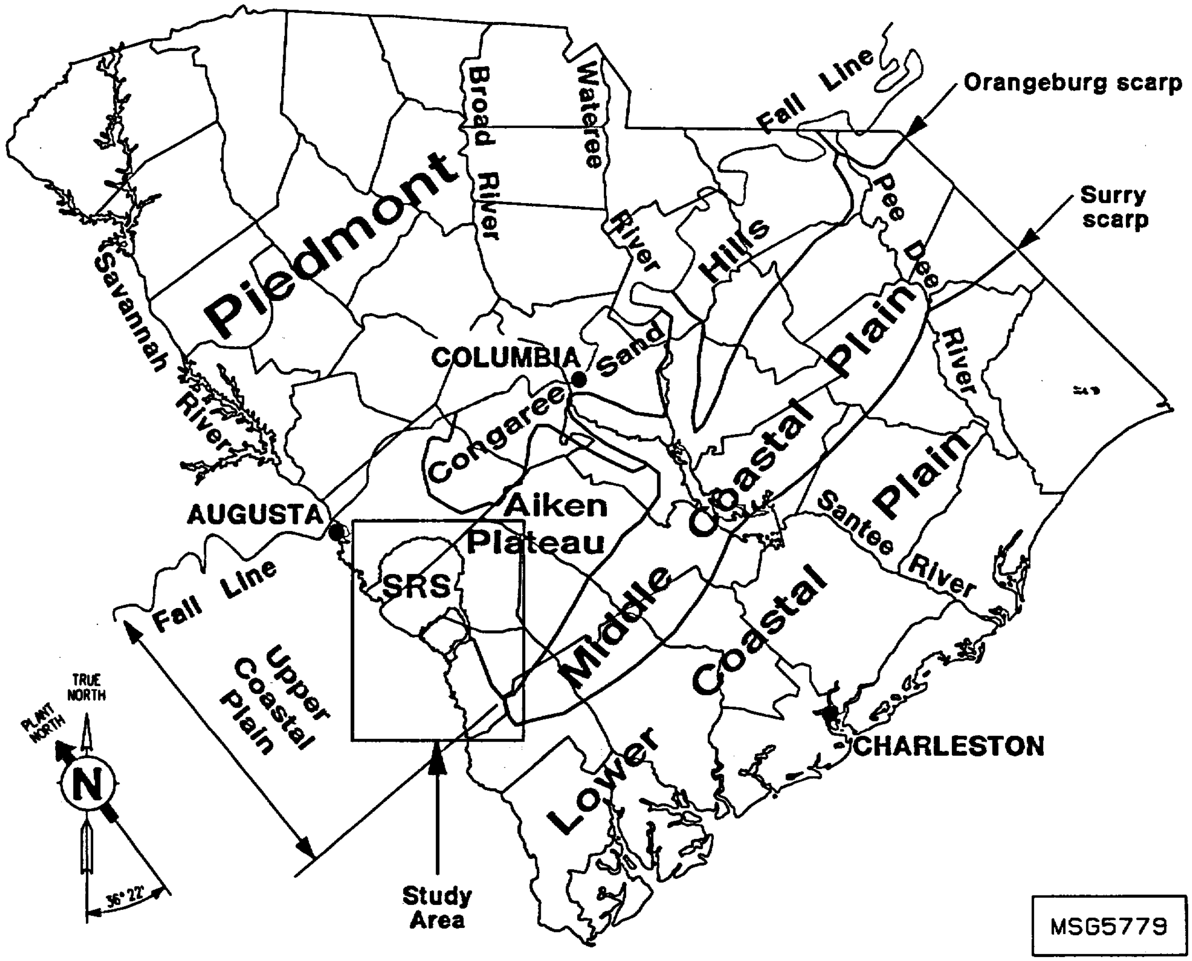

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Figure 1.3.5-15. Regional Physiographic Provinces of South Carolina

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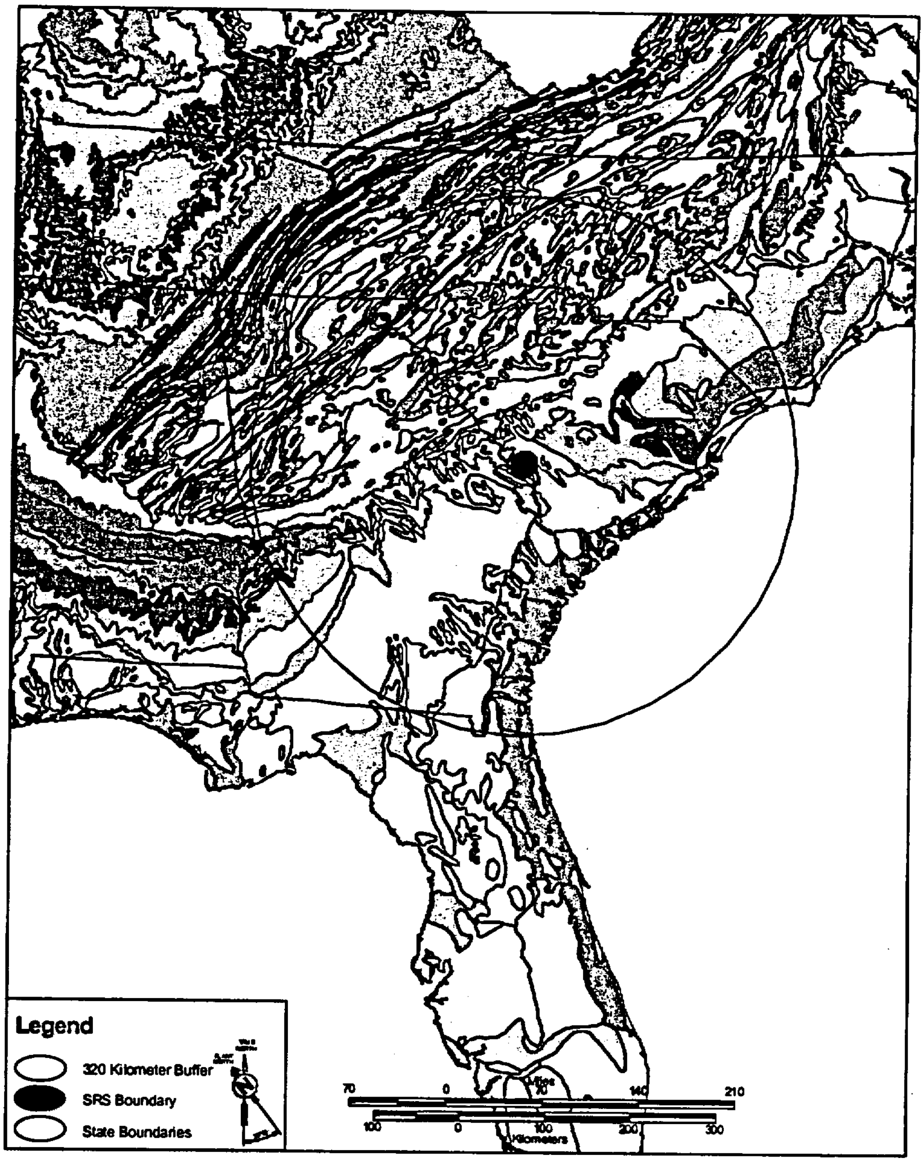

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Figure 1.3.5-16. Regional Geologic Map of the Southeastern United States

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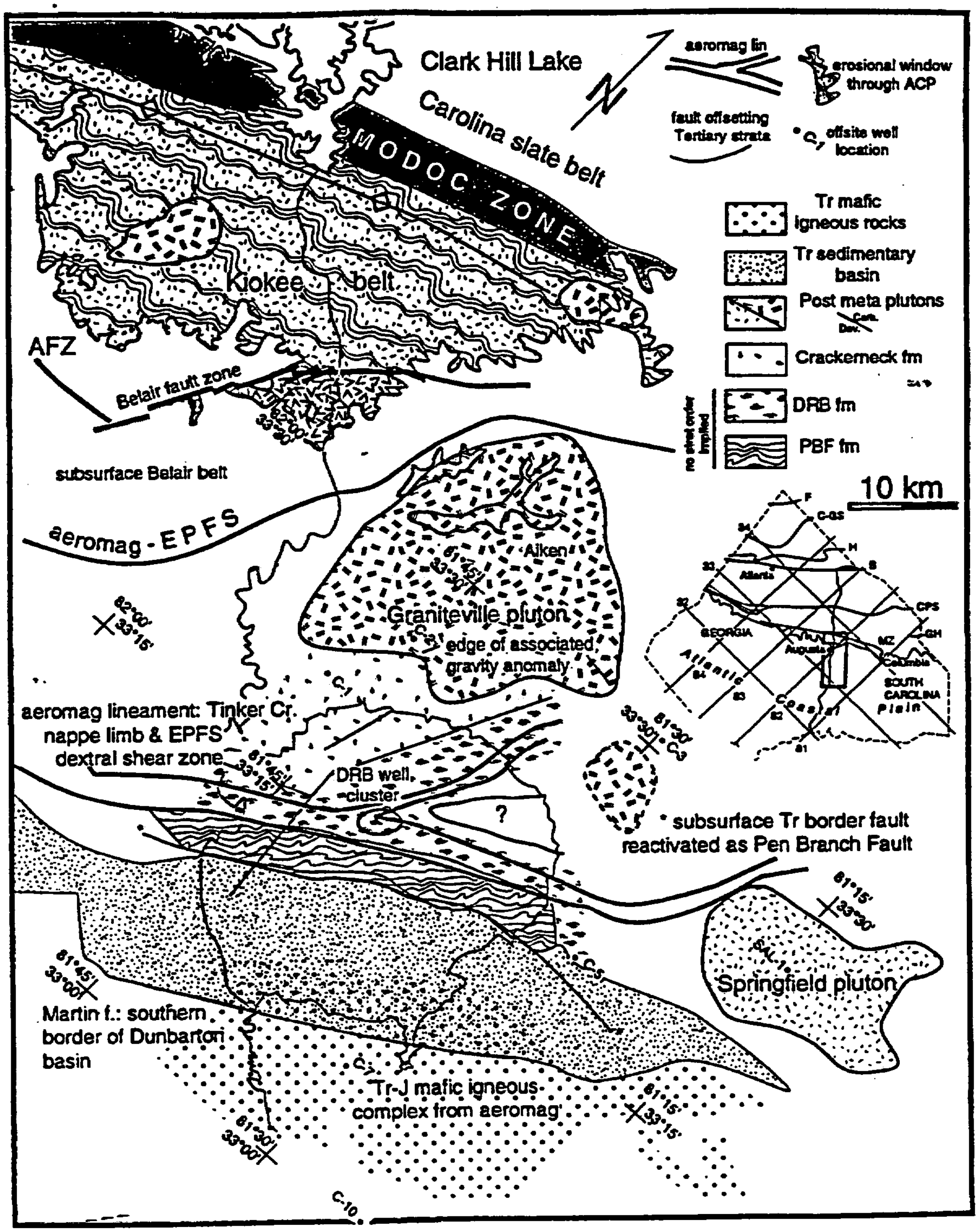

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Figure 1.3.5-17. Geologic Map of Basement Lithologies Beneath SRS and Vicinity With Adjacent Piedmont

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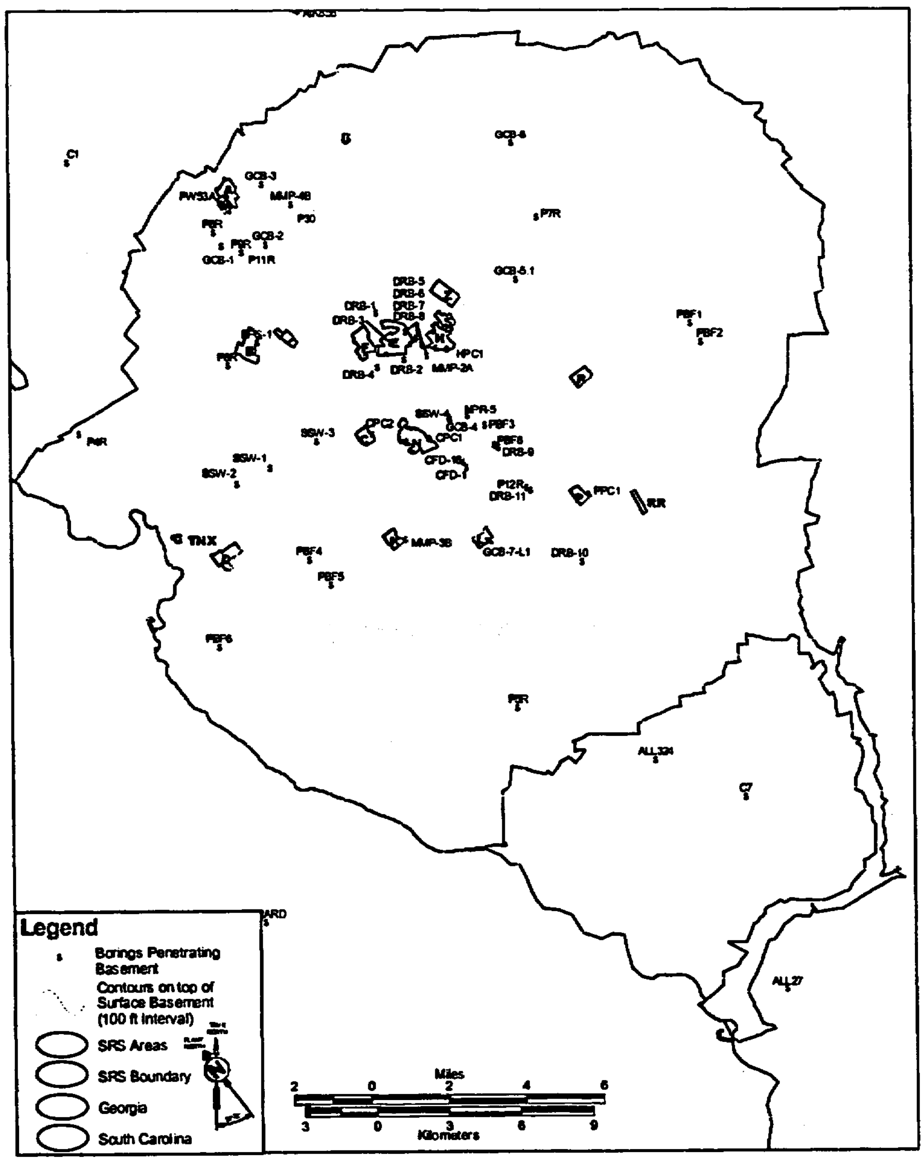

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Figure 1.3.5-18. Map of the Basement Surface at SRS

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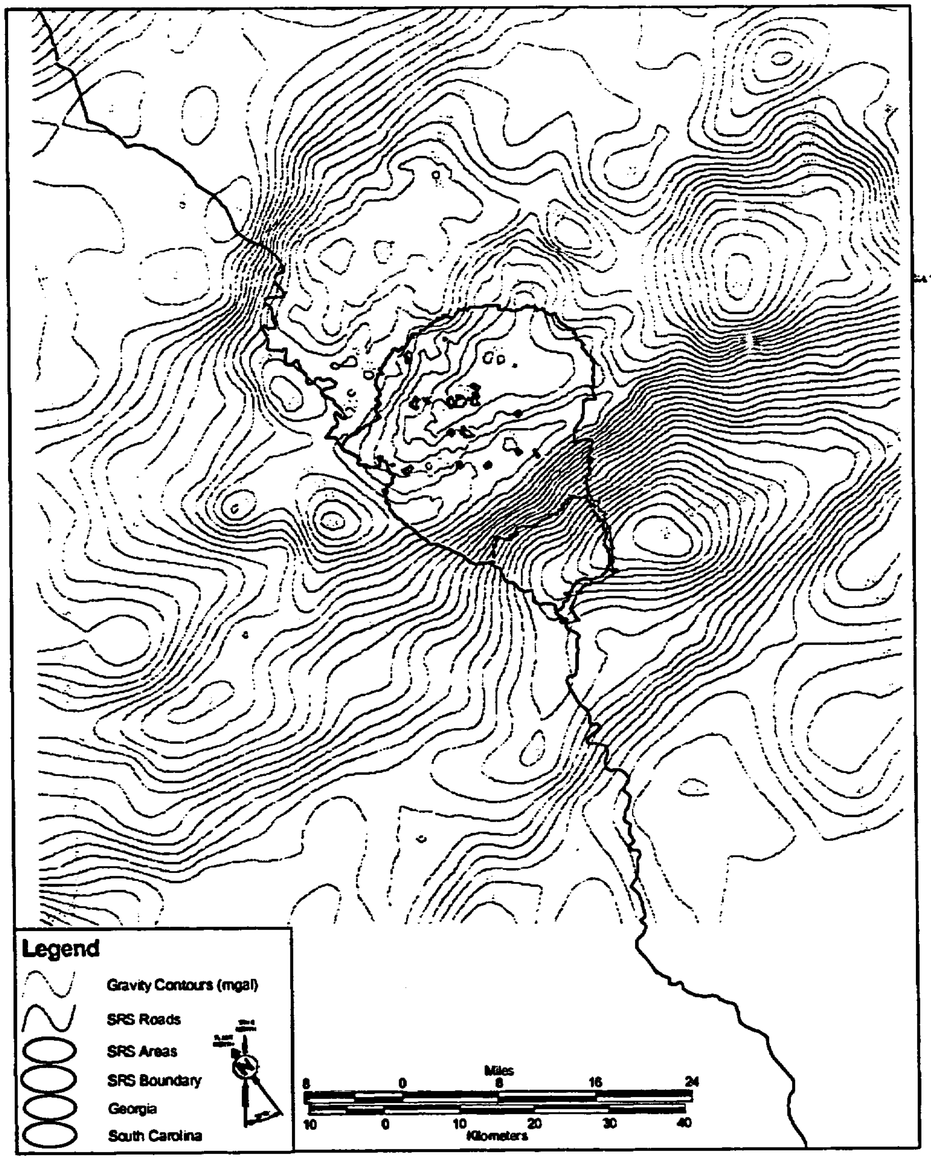

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Figure 1.3.5-19. Free Air Gravity Anomaly Map for SRS and Vicinity (40 km radius)

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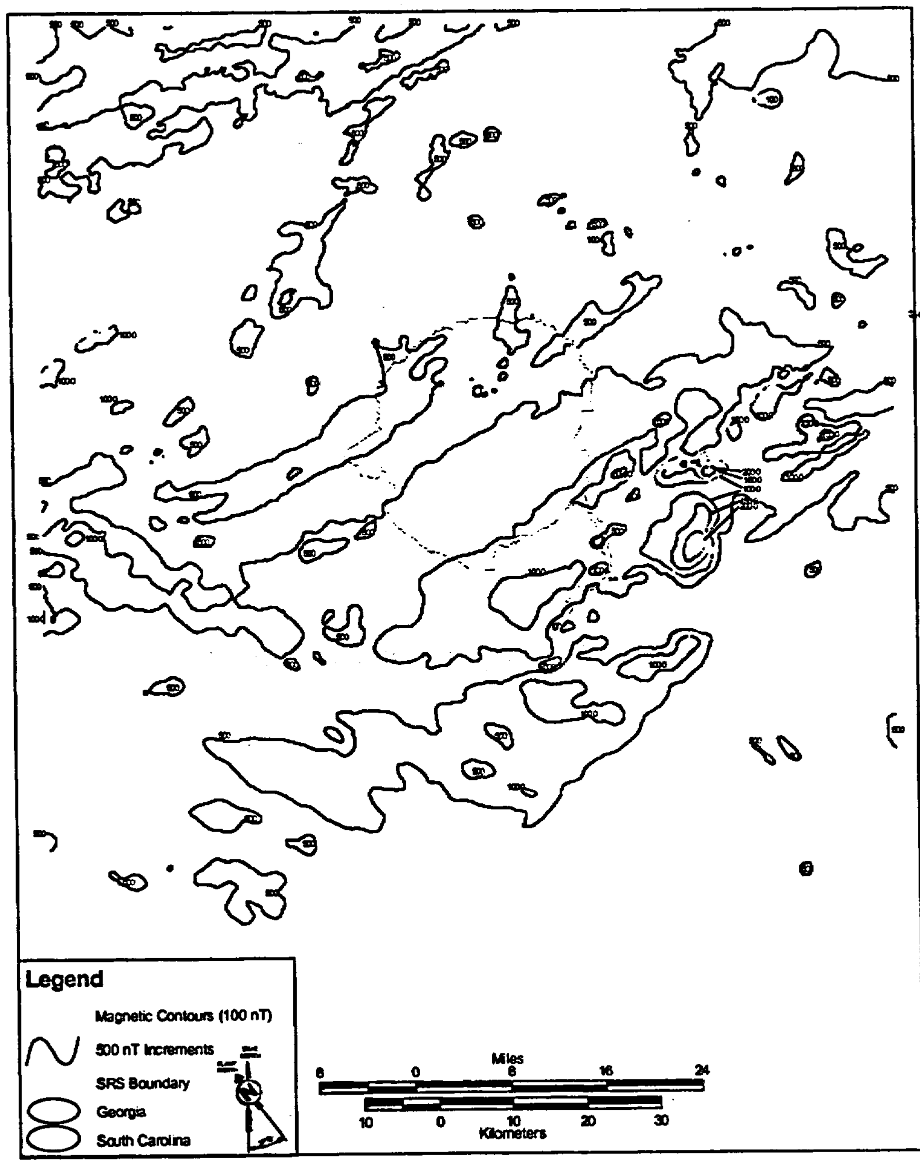

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Figure 1.3.5-20. Aeromagnetic Anomaly Map for SRS and Vicinity (40 km radius)

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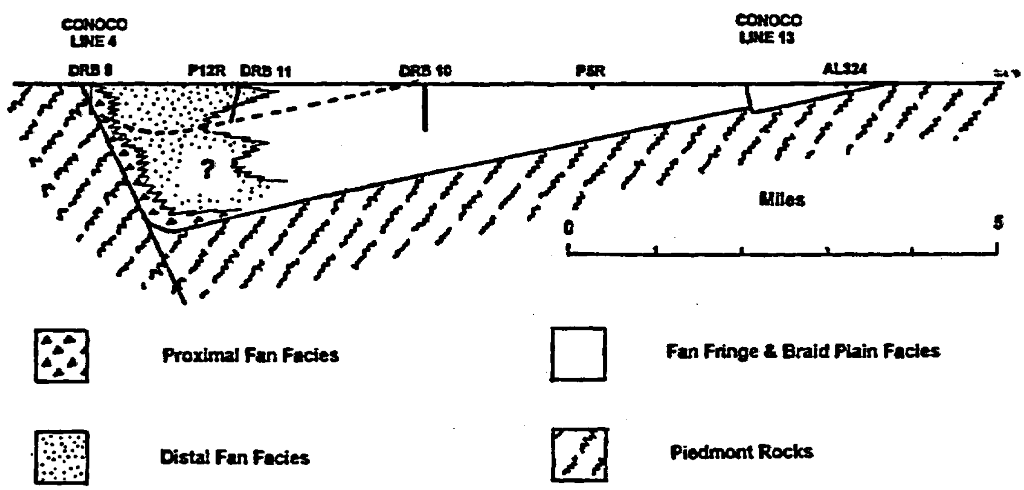

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Figure 1.3.5-21. Generalized Geologic Cross Section of the Dunbarton Basin

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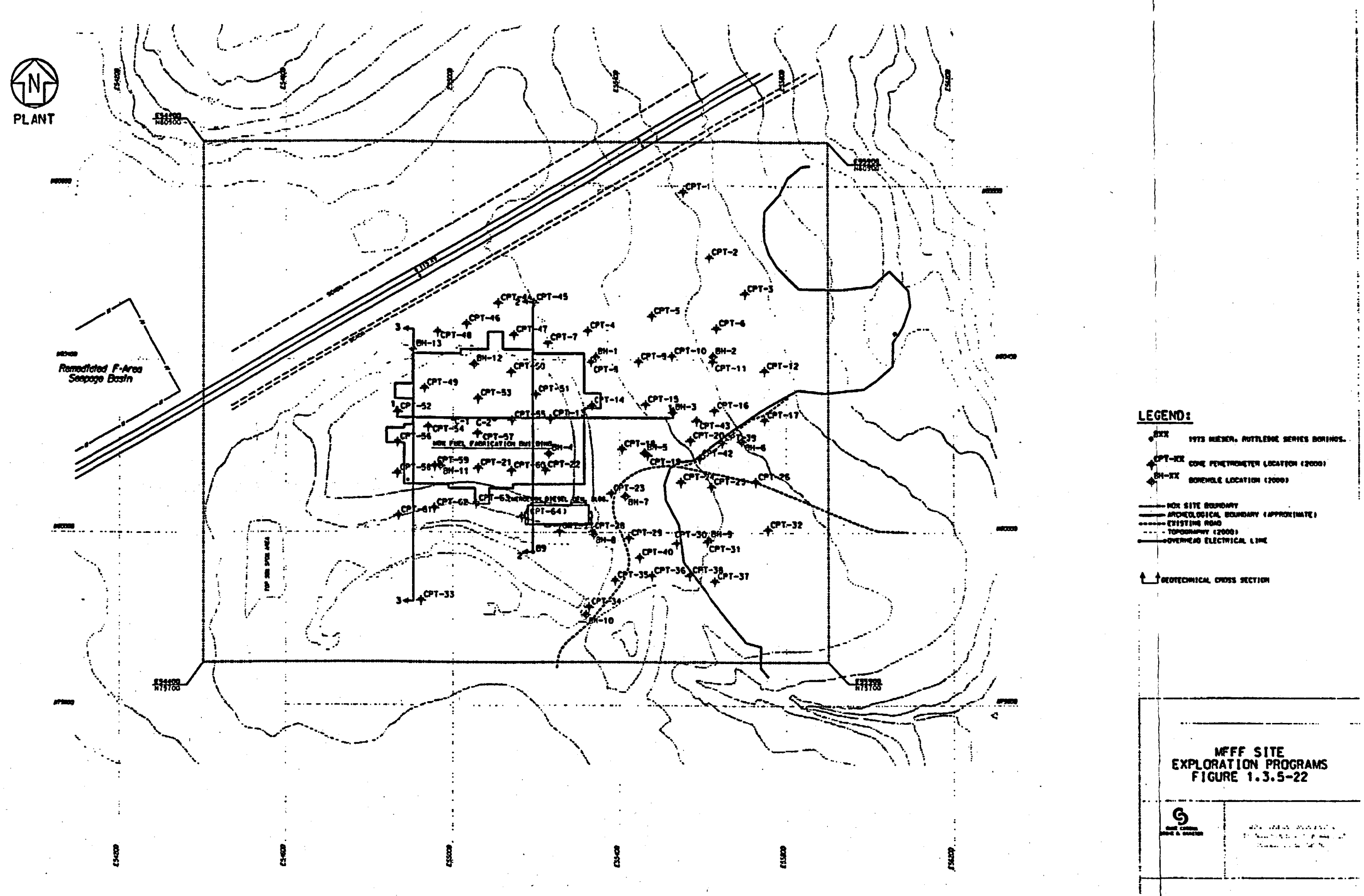

Figure 1.3.5-22. MFFF Site Exploration Programs

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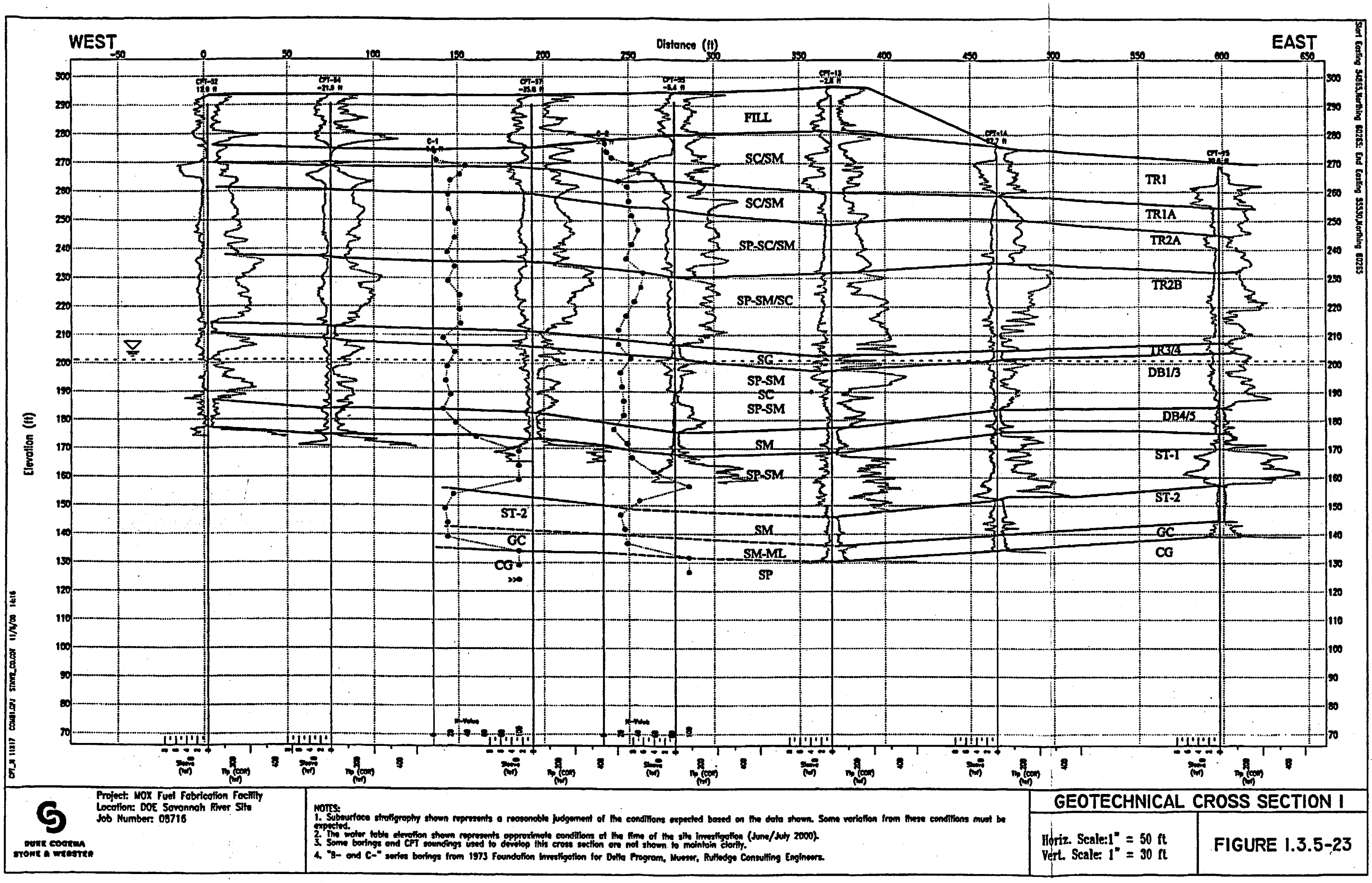

Figure 1.3.5-23. Geotechnical Cross Section 1

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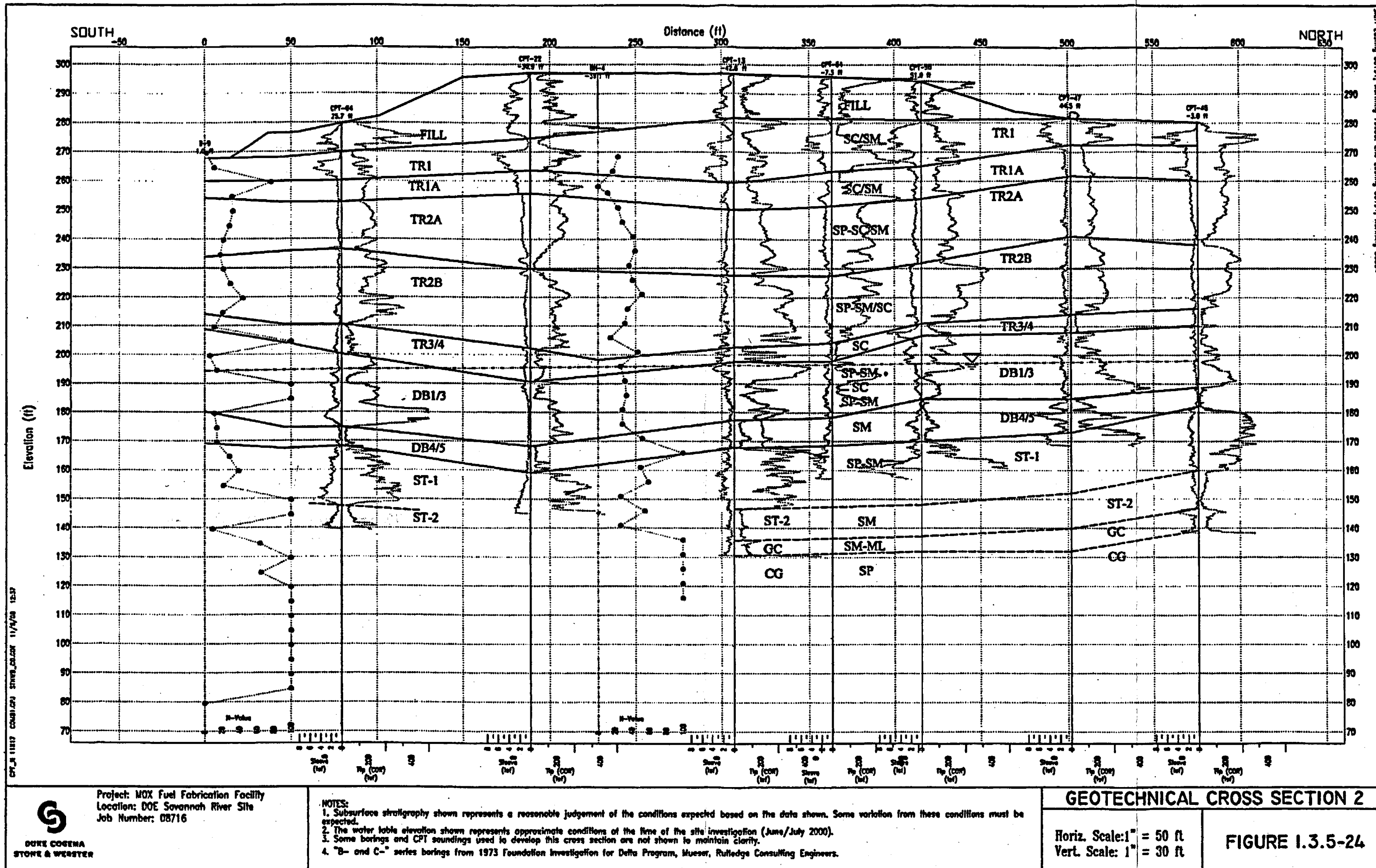

Figure 1.3.5-24. Geotechnical Cross Section 2

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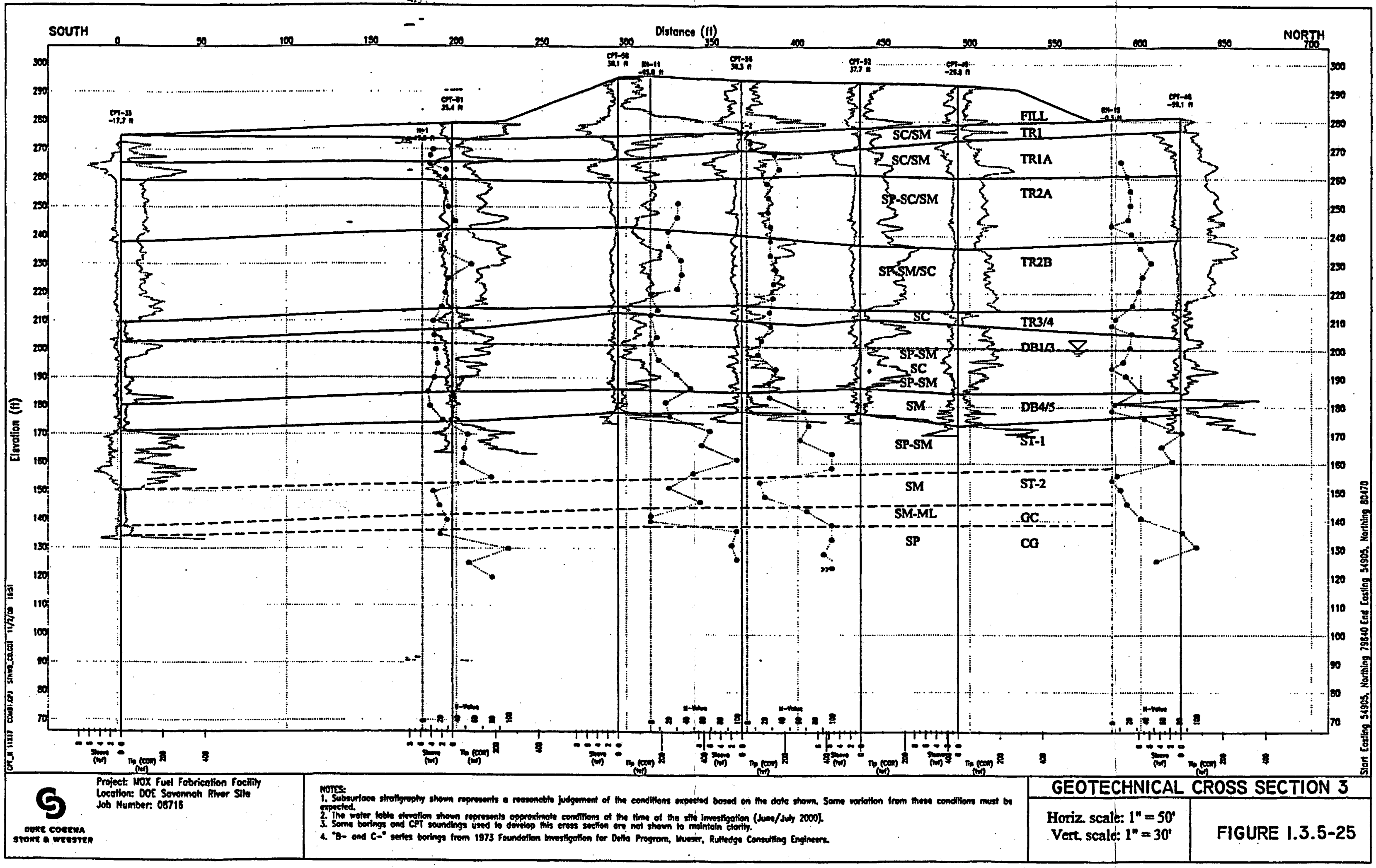

Figure 1.3.5-25. Geotechnical Cross Section 3

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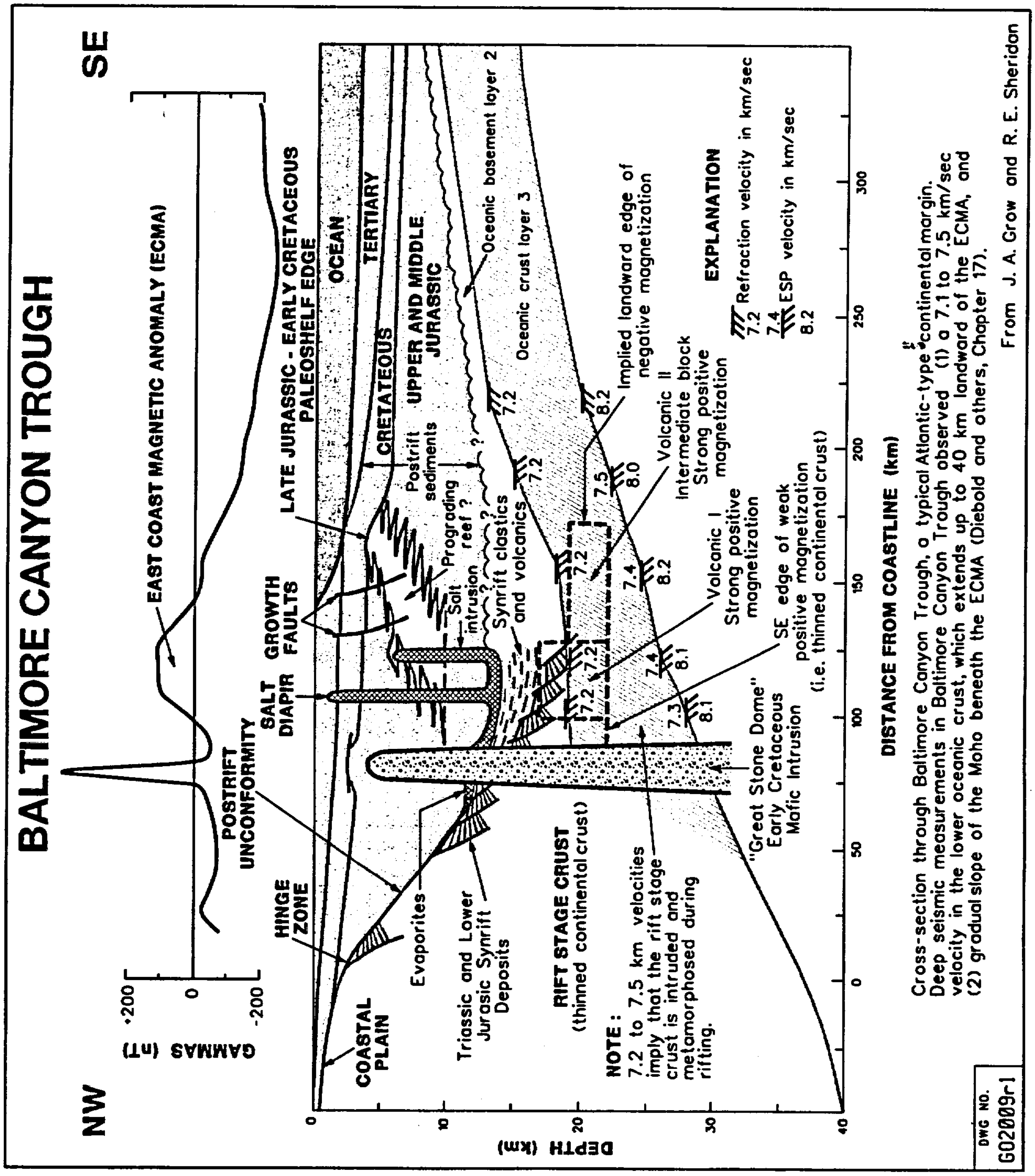

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Figure 1.3.5-26. A Cross-Section Through the Continental Margin and Baltimore Trough (offshore New Jersey)

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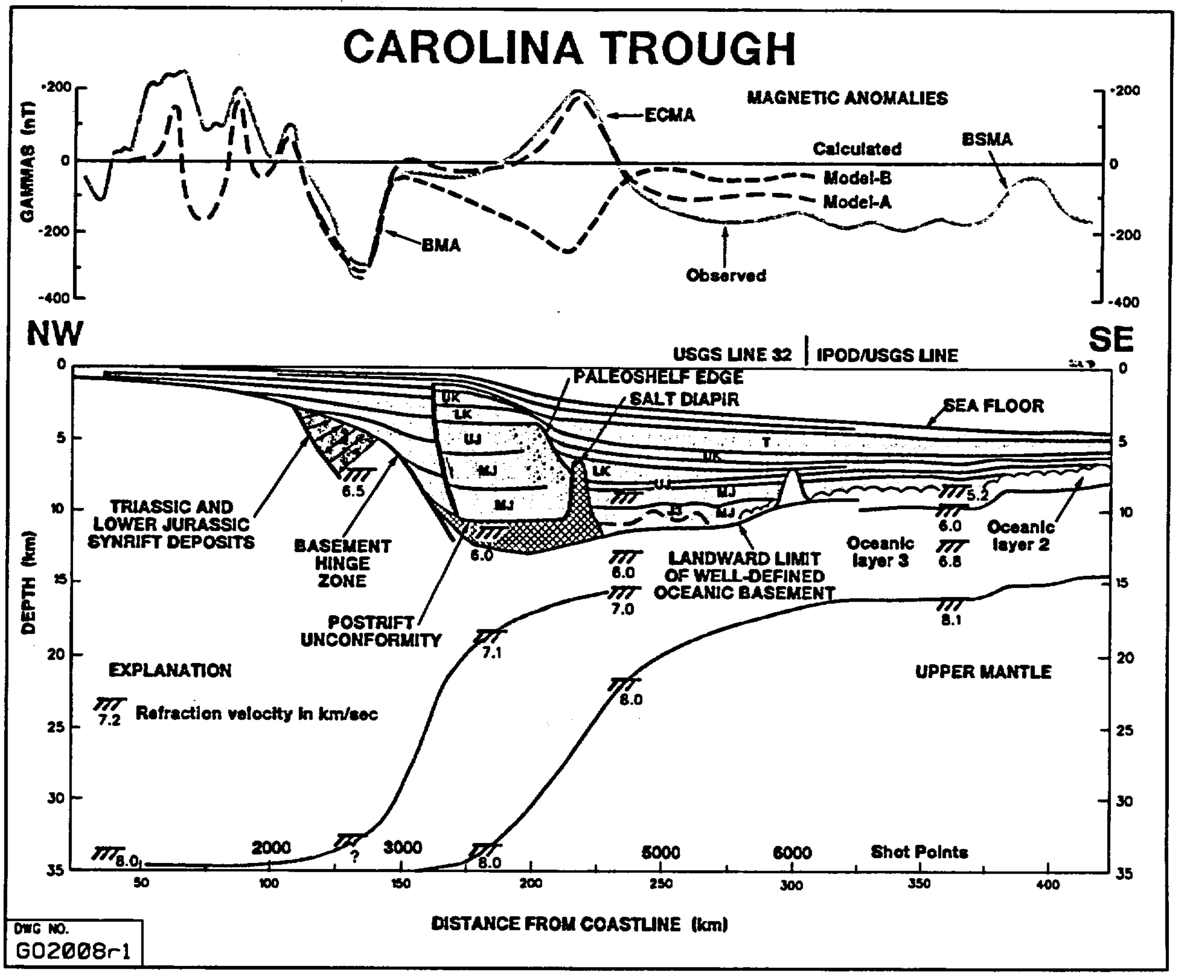

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Figure 1.3.5-27. Crustal Geometry for Offshore South Carolina and North Carolina Show a Geometry of Thinning Crust

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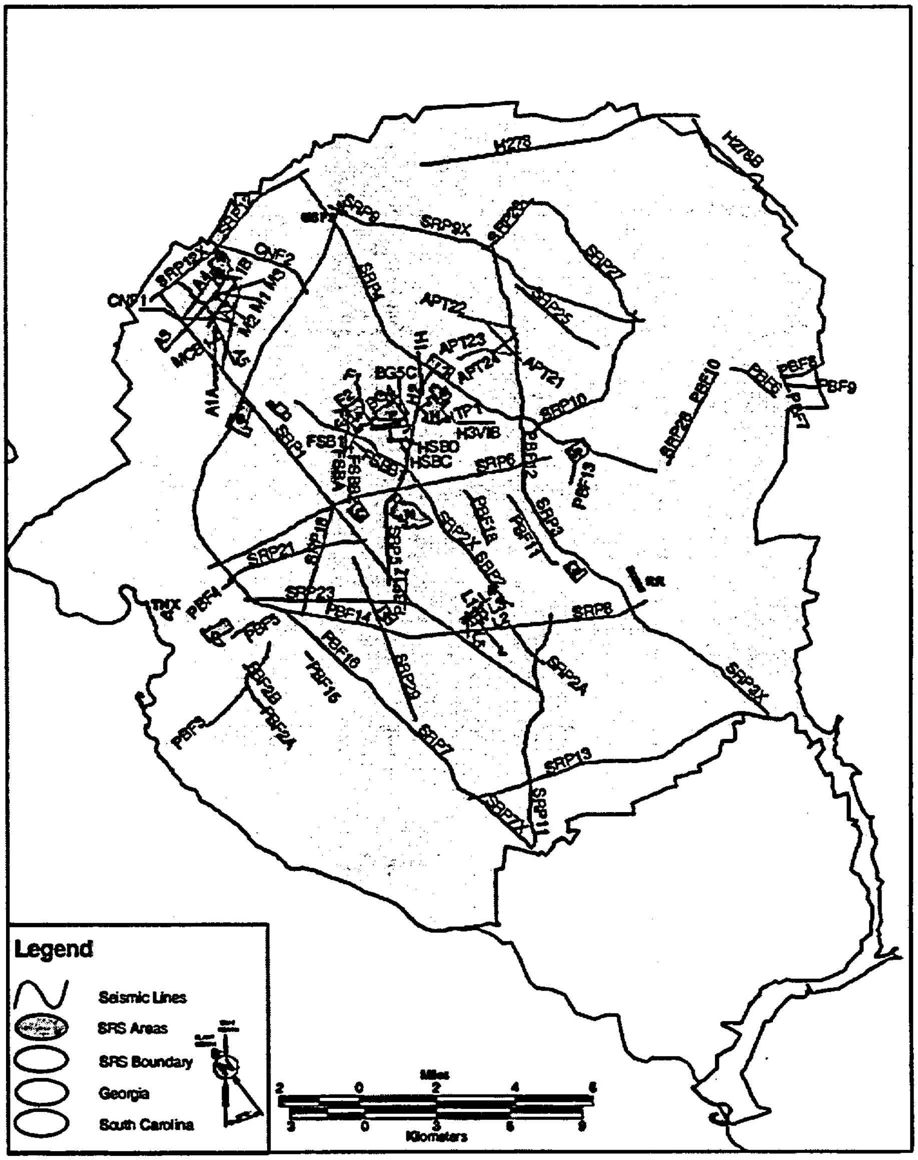

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Figure 1.3.5-28. Seismic Line Coverage (location of seismic reflection data) for the Savannah River Site

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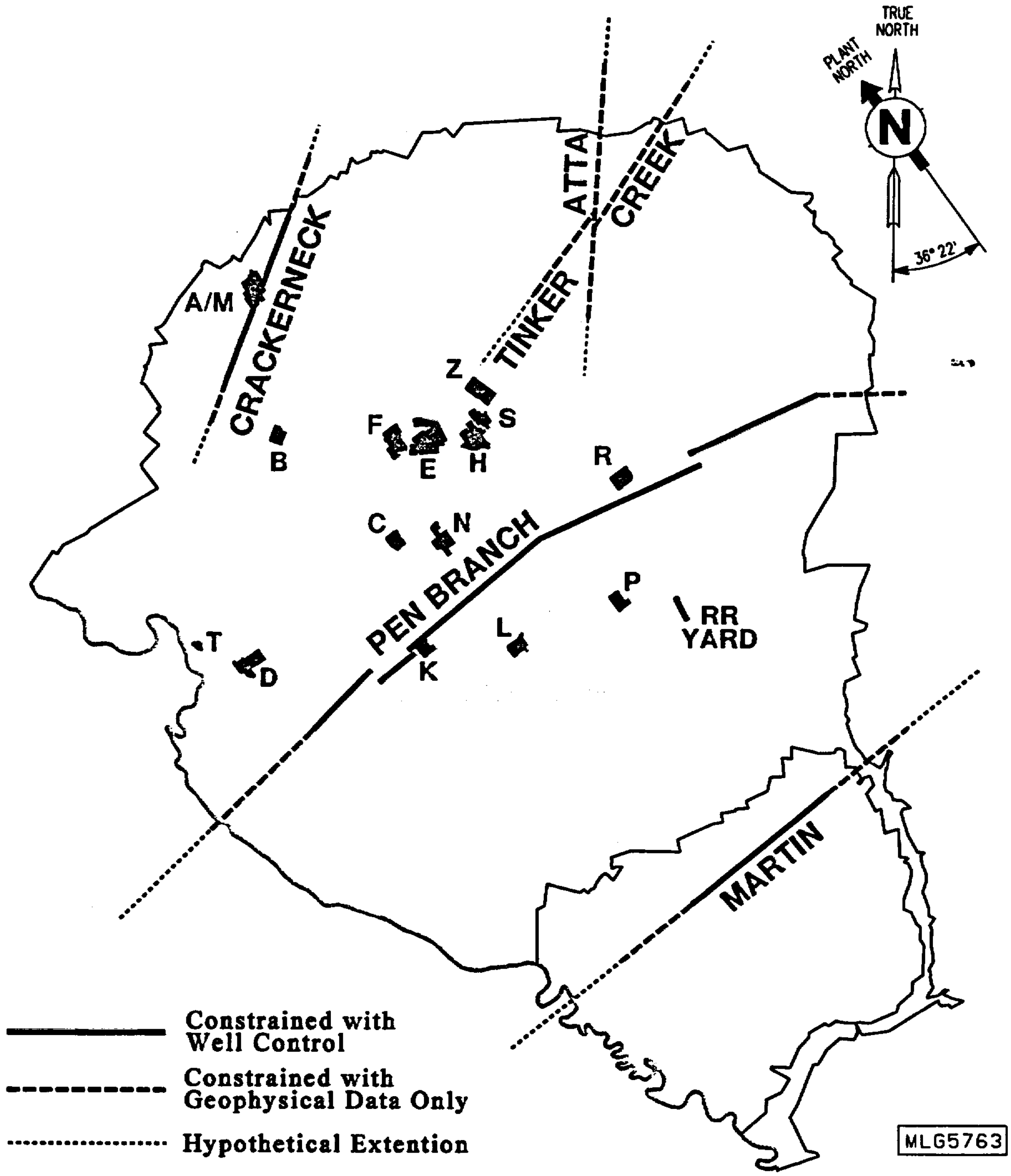

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Figure 1.3.5-29. Regional Scale Faults for SRS and Vicinity

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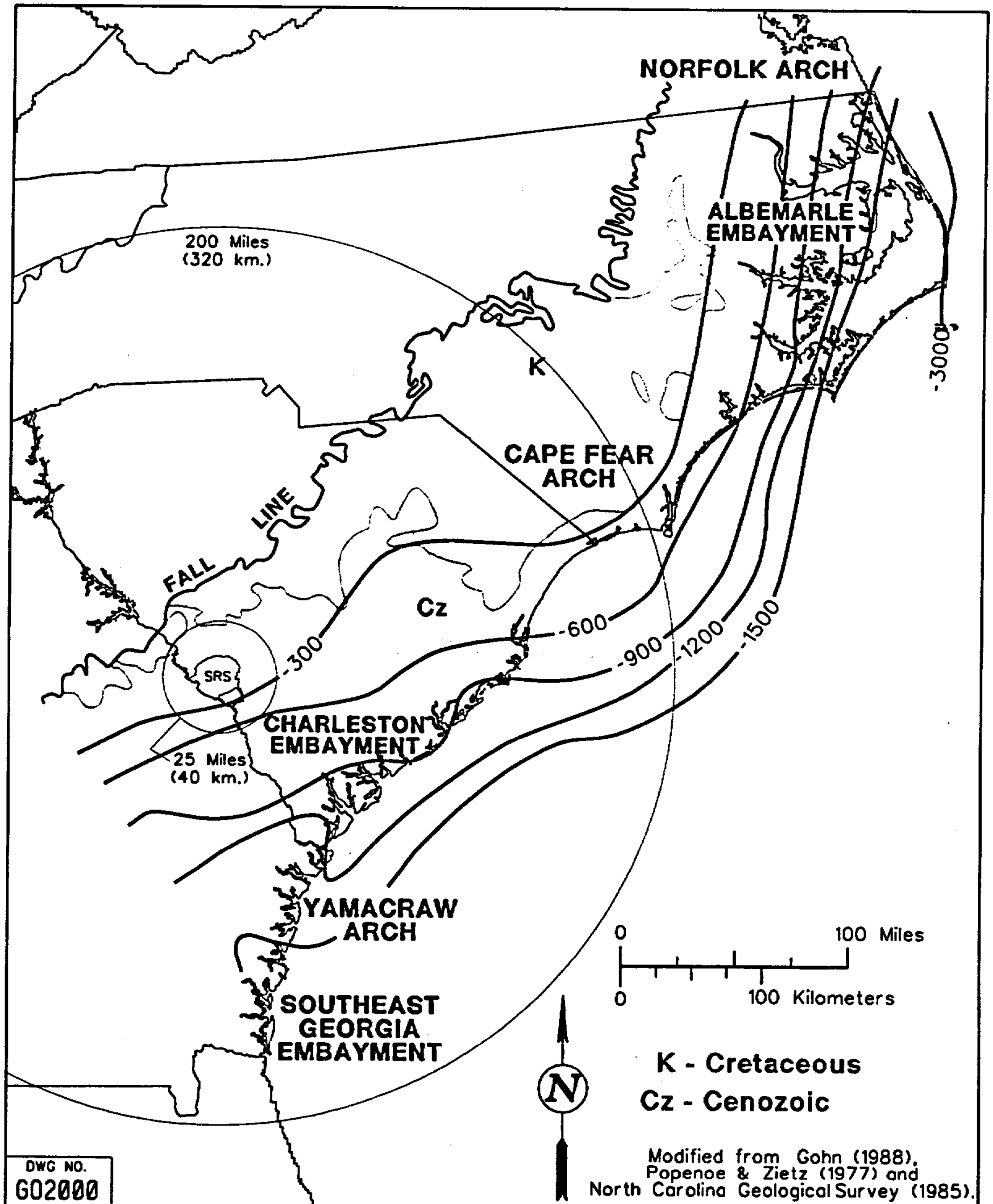

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Figure 1.3.5-30. The Cape Fear Arch Near the North Carolina-South Carolina Border

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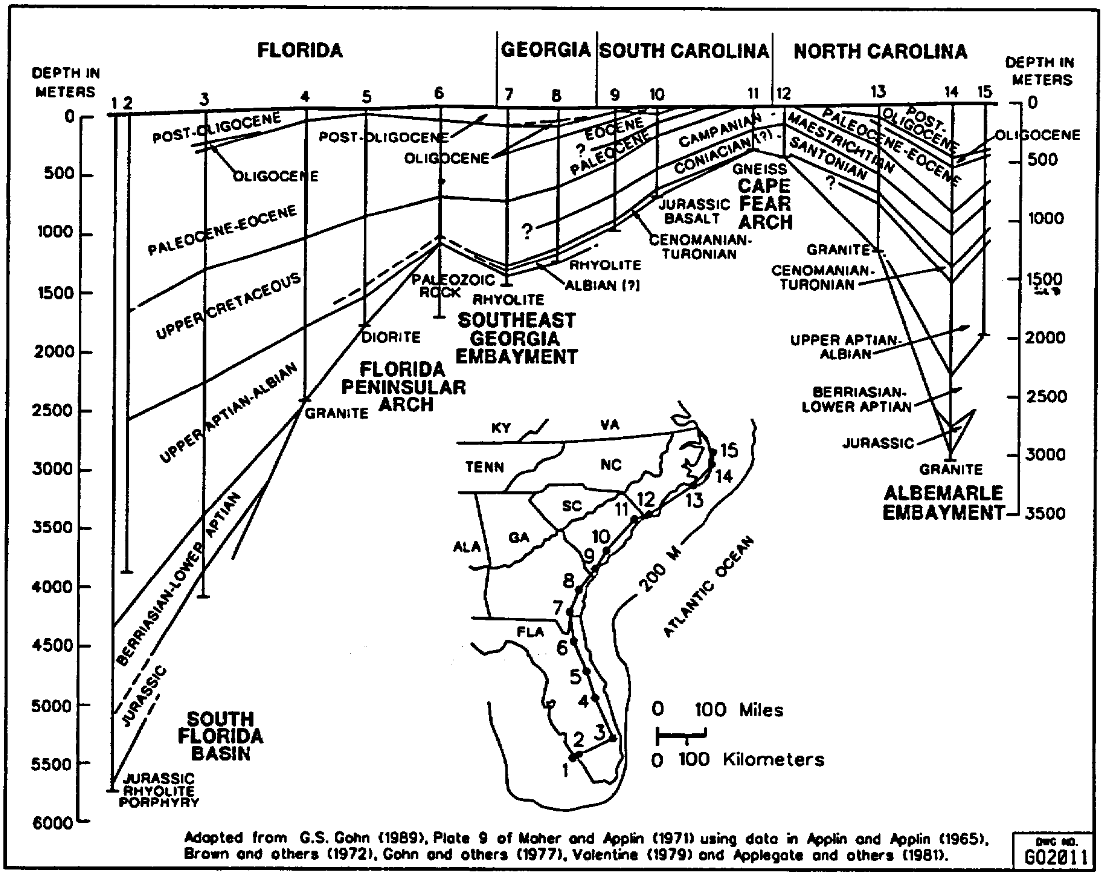

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Figure 1.3.5-31. Other Arches in the Region Include the Norfolk Arch Near the North Carolina-Virginia Border, and the Yamacraw Arch Near the South Carolina-Georgia Border

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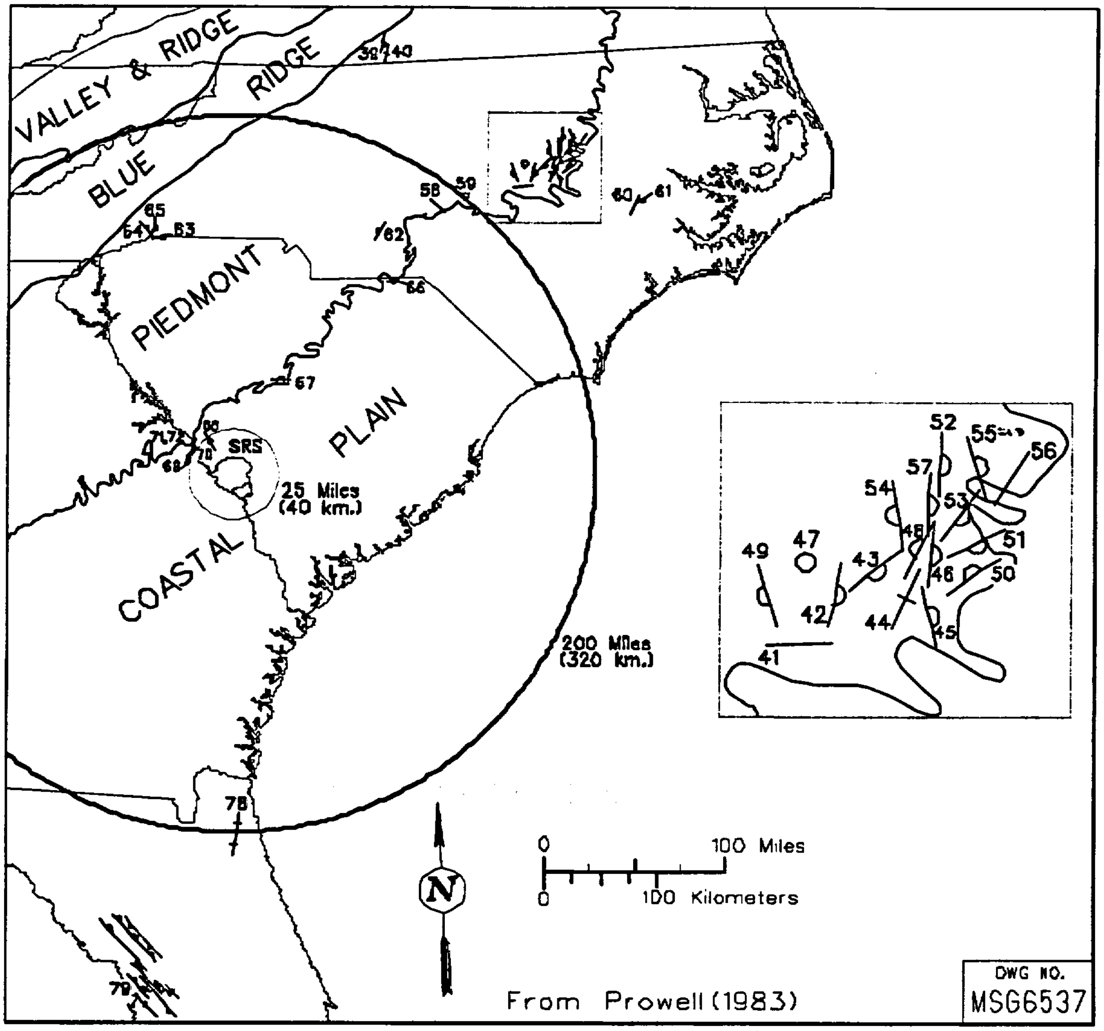

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Figure 1.3.5-32. Faults That Involve Coastal Plain Sediments That Are Considered Regionally Significant Based on Their Extent and Amounts of Offset

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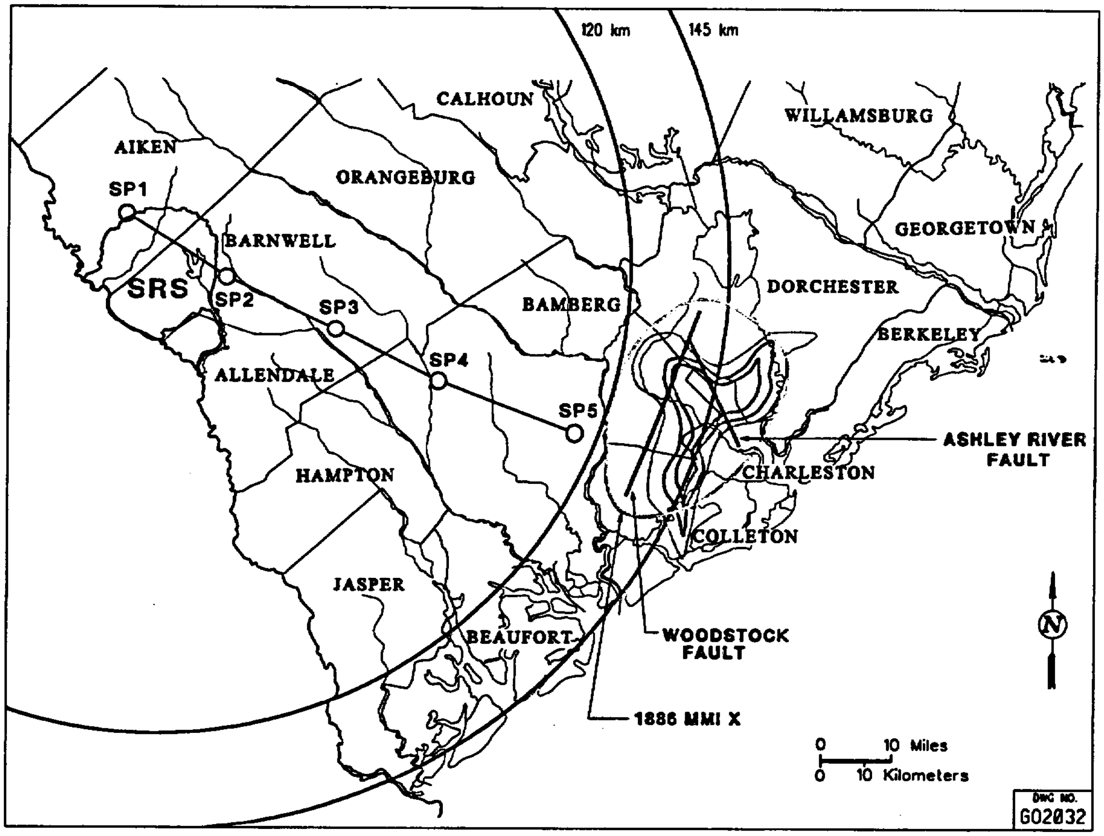

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Figure 1.3.5-33. Ashley River/Woodstock Faults

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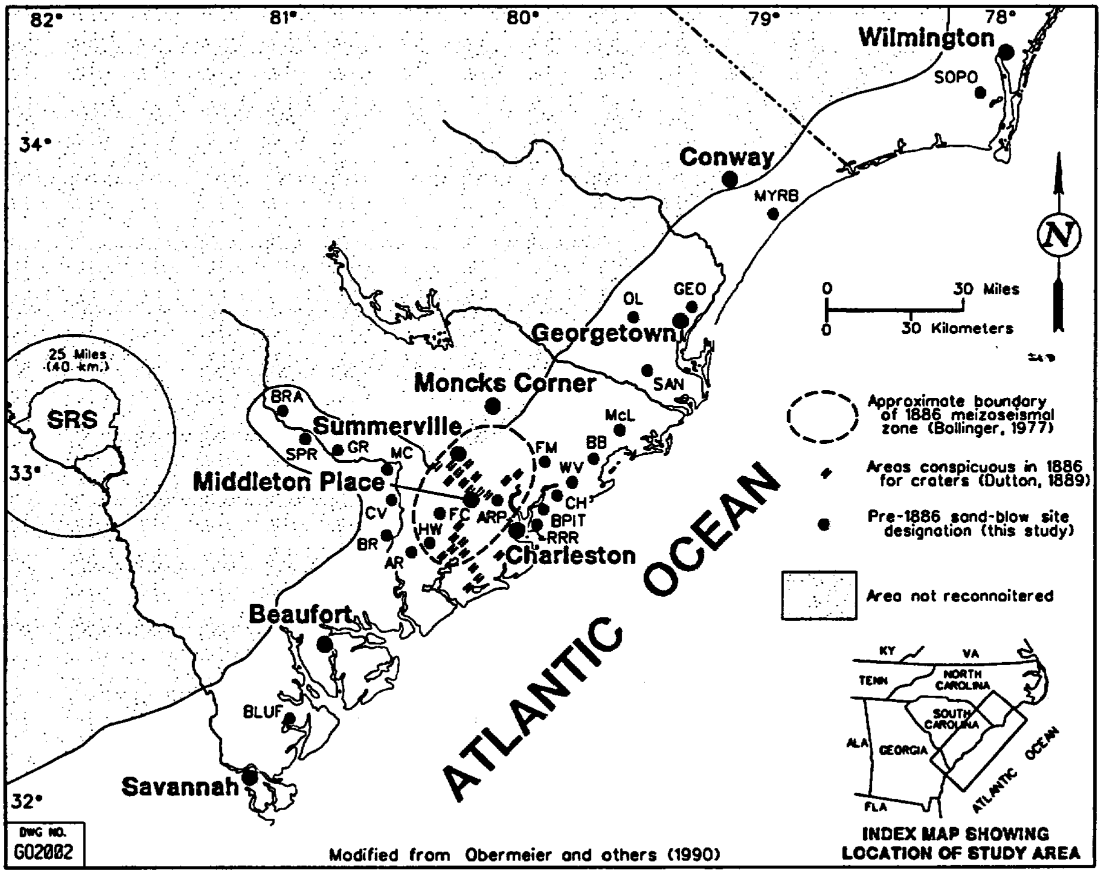

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Figure 1.3.5-34. Location of Sand Blows

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1.3.6 Seismology

Significant studies of the local and regional seismology for SRS have been conducted to support operation of DOE facilities there. The MOX project has used these studies as a starting point in establishing appropriate design inputs for the MFFF. This section presents criteria that have been developed for DOE facilities at SRS, and their application to developing design criteria for the MFFF.

Section 1.3.6.1 presents a broad description of the historic seismic record of the southeastern United States and SRS. This section also describes in detail the pre-instrumental and post-instrumental seismic records for SRS and the surrounding area. Section 1.3.6.2 discusses the relationship between geologic structure and seismic sources within the general site region. Section 1.3.6.3 summarizes the phased development of the seismic criteria for SRS facilities. Section 1.3.6.4 briefly describes the methodology used for ground motion prediction, earthquake source, path and site assumptions for H Area, and the most recent design basis earthquake (DBE) work conducted for SRS. Section 1.3.6.5 shows the current design criteria for DOE facilities, and Section 1.3.6.6 defines the MFFF design earthquake.

1.3.6.1 Earthquake History of the General Site Region

This section presents a broad description of the historic seismic record (non-instrumental and instrumental) of the southeastern United States and SRS. Aspects that are of particular importance to SRS and the MFFF site include the following:

- The Charleston, South Carolina, area is the most significant seismogenic zone affecting SRS.
- Seismicity associated with SRS and the surrounding region is more closely related to South Carolina Piedmont-type activity. This activity is characterized by occasional small shallow events associated with strain release near small-scale faults, intrusive bodies, and the edges of metamorphic belts.

1.3.6.1.1 Historic Record

The earthquake history of the southeastern United States (of which SRS is a part) spans a period of nearly three centuries and is dominated by the catastrophic Charleston earthquake of August 31, 1886. The historical database for the region is essentially composed of two data sets extending back to as early as 1698. The first set is comprised of pre-network, mostly qualitative data (1698 to 1974), and the second set covers the relatively recent period of instrumentally recorded or post-network seismicity (1974 to present). A comprehensive catalog was created that successfully merged macroseismic, historical pre-network data with instrumental, mostly microseismic, post-network data. Table 1.3.6-1 lists significant earthquake locations within 200 mi (322 km) of SRS excerpted from this catalog. Today, seismic monitoring results from all southeastern seismic networks are cataloged annually in the Southeast U.S. Seismic Network (SEUSSN) bulletins. This catalog is considered to be the most complete listing of seismic events for the Southeastern U.S. region. Other catalogs are available, and differences exist between catalogs, but the noted differences have no impact on the assessment of SRS. Figure 1.3.6-1 shows both pre-network and post-network locations of activity for the southeastern United States, from 1568 to 1993, within a 200-mi (322-km) radius of SRS.

The information chronicled on earthquakes within the Southeast and the SRS region during the pre-network period consists of intensity data. Intensity refers to the measure of an earthquake's strength by reference to "intensity scales" that describe, in a qualitative sense, the effects of earthquakes on people, structures, and land forms. A number of different intensity scales have been devised over the past century, but the scale generally used in North America and many other countries is the modified Mercalli (MMI) Scale (Table 1.3.6-2). Using this intensity scale, it is possible to summarize the macroseismic data for an earthquake by constructing maps of the affected region that are divided into areas of equal intensity. These maps are known as isoseismal maps. It was through construction of isoseismal maps that epicenters of pre-network earthquakes were located at or near centers of areas experiencing highest ground shaking intensity. There is considerable uncertainty (up to several tens of miles) in locating the epicenters with this method because it depends heavily upon population density of the region in which the earthquake occurred.

The Charleston, South Carolina, area is the most significant source of seismicity affecting SRS, in terms of both the maximum historical site intensity and the number of earthquakes felt at SRS. The greatest intensity felt at SRS has been estimated at MMI VI-VII and was produced by the intensity X earthquake that struck Charleston, South Carolina, on August 31, 1886, at 9:50 p.m. local time (see Figure 1.3.6-2). An earthquake that struck Union County, South Carolina (about 100 mi [161 km] north-northeast of SRS), on January 1, 1913, is the largest event located closest to SRS outside of the Charleston area. It had an intensity greater than or equal to MMI VII. This earthquake was felt in the Aiken-SRS area with an intensity of MMI II-III. Several other earthquakes, including some aftershocks of the 1886 Charleston event, were felt in the Aiken-SRS area with intensities estimated to be equal to or less than MMI IV.

Several large earthquakes outside the region were probably felt at SRS, including the earthquake sequence of 1811 and 1812 that struck New Madrid, Missouri (about 535 mi [861 km] west-northwest of SRS) and the earthquake that struck Giles County, Virginia (about 280 mi [451 km] north of SRS), on May 31, 1897. The temporal completeness of the existing earthquake catalog is considered to be complete for recent network data to mb = 2.5, the historical period between 1939 and 1977 complete to mb = 4.5, and the historical period between 1870 and 1930 complete to mb = 5.7.

1.3.6.1.1.1 SRS Activity (within 50-mi [80-km] Radius)

SRS is located within the Coastal Plain physiographic province of South Carolina. However, seismic activity associated with SRS and the surrounding region displays characteristics more closely associated with the Piedmont province (i.e., a marked lack of clustering in zones). The activity is more characteristic of the occasional energy strain release occurring through a broad area of central Piedmont of the state. Epicentral locations for events near (within 50 mi [80-km] from the center of the site) SRS are presented in Table 1.3.6-3. Figure 1.3.6-3 shows the distribution of earthquake epicenters within 50 mi (80 km) of SRS.

Each historical event is described below. The numbers in parentheses refer to numbers on Figure 1.3.6-3 and Table 1.3.6-3.

1897, May 06, 24, and 27 (1,3,4): These three small earthquakes were reported to have occurred around the farming community of Blackville, South Carolina. They were lightly felt by residents of the town and surrounding farms. No intensity values have been assigned to these events because they have only been mentioned as being felt. When researching local newspapers of the area, the only reference found to any of these small events appeared as a small sentence in the May 13 issue of the *Barnwell People* from Blackville, which said, "Quite an earthquake shock was felt here on last Friday evening at 8:10." No mention of the 24th or 27th events was found in newspapers published shortly following those dates.

1897, May 09 (2): This has been documented as a small "lightly" felt event in the area of Batesburg, South Carolina. No intensity values have been assigned to this event.

1945, July 26: This event was felt mostly in the Columbia and Camden, South Carolina, areas. Historically, this event has been more closely associated with Lake Murray, near Columbia, South Carolina. However, it was relocated using some instrumental recordings at regional and teleseismic distances. Relocation moved the epicenter some 31 mi (50 km) to an area southwest of Columbia and to within the 50-mi (80-km) radius of interest for this study. This location, though instrumental, seems extremely questionable. An isoseismal map for this event defined the area of greatest intensity (VI) to be near Camden, South Carolina. Newspaper reports from Aiken, Columbia, and Camden in South Carolina the day following the event tend to confirm this original location. In this case, the location indicated from the reports of the intensity experienced is favored over the instrumental location.

1972, August 14 (5): This earthquake was reported to have been felt in Barnwell, Bowman, Cordova, Horatio, North, Springfield, and Summerton, South Carolina, with an intensity of between I and III. The location of this earthquake also seems tenuous. Although the event was instrumentally located, the location can only be assumed approximate because the nearest station was over 62 mi (100 km) northeast of the computed epicenter. This event may possibly have occurred closer to the Bowman area and outside the area of interest for this study.

1974, October 28 (6) and November 5 (7): These two events were estimated to have occurred in McCormick and southern Edgefield Counties, South Carolina. Magnitudes of 3.0 and 3.7, respectively, were assigned on the basis of felt reports collected at the time. An isoseismal map for the October event shows an elongated isoseismal roughly following the Fall Line with a maximum felt intensity of III-IV. No instrumental locations are available for either of these events.

1.3.6.1.2 Instrumental Record (Post-Network Seismicity)

By the middle of the 20th century, instrumental recordings from a few regional seismographic stations (less than ten for the entire southeastern United States) reduced uncertainty in locating epicenters to fewer than 10 mi (16 km). However, it was not until the early 1970s that the detection and location of earthquakes in the region greatly improved with the installation of seismic networks in South Carolina, as well as other regions of the eastern United States.

The first seismic network in the region was deployed by the USGS and the University of South Carolina in 1974. Operation continues today under the management of the University of South Carolina and is known as the South Carolina Seismic Network. It currently consists of some 28 stations strategically located throughout the state. By 1976, a three-station short-period vertical component network was also established at SRS to monitor potential earthquake activity near SRS. A fourth station, consisting of a vertical and two horizontal instruments, was added to the network in 1986. Figure 1.3.6-4 shows the current station configuration of the SRS short-period seismic recording stations.

With the advent of modern seismic network installation, it was possible to estimate local magnitudes from collected data. Magnitudes are more quantitative estimates of an earthquake's size using instrumentally recorded data. They are based on the amplitude of motion on a standard instrument (seismograph) normalized to account for the separation of the instrument and the earthquake. Within South Carolina and the SRS region, the University of South Carolina developed a duration magnitude scale normalized to the worldwide seismic station in Atlanta, Georgia, that has been commonly employed since the mid-1970s within South Carolina and the SRS region. Magnitudes reported using the duration scale are approximately equivalent to body wave magnitude. The uncertainty in the instrumentally determined duration magnitudes is about +0.3 magnitude units.

In addition to more accurate determinations of epicenters and magnitudes, a major benefit of instrumentation has been the ability to determine focal depths and focal mechanisms of locally recorded earthquakes. There is a systematic difference between the depths of earthquakes occurring in the Appalachian highlands and those occurring in the Piedmont and Coastal Plain. In the Appalachian highlands, the 90% depth (i.e., the depth above which 90% of all foci lie) is 12 mi (19.3 km), with a peak in the focal depth distributions at 6 to 7 mi (9.6 to 11.3 km). The corresponding depths for Piedmont and Coastal Plain earthquakes are 8 mi (12.9 km) and 4 to 5 mi (6.4 to 8 km), respectively. It has been argued that these depth variations indicate a significant difference in the thickness of the seismogenic crust between the adjacent provinces. Focal mechanism data for the region have been presented by many researchers through the years. Most focal mechanisms for the South Carolina-SRS region can be summarized to indicate thrust or strike-slip faulting, with the direction of the P-axis (inferred to be the direction of maximum horizontal compressive stress, oriented in a northeast-southwest to east-northeast, west-southwest direction). An updated summary of existing fault mechanism results is presented in Figure 1.3.6-5.

1.3.6.1.3 Instrumental Locations (Post-Network)

A detailed review of all existing data pertaining to instrumentally located earthquake activity within 50 mi (80 km) of SRS has recently been completed. The purpose of the review was to refine as much as possible the locations of reported event locations, both historical and instrumental. Historical activity was addressed above in the previous section, and with the exception of the 1945 event, the number of reported occurrences and locations did not change. Examination of data associated with instrumentally obtained epicenters revealed that many of the reported events would benefit from using a more detailed velocity model developed since the locations were originally noted. Additionally, waveform data not employed in some of the original locations was added from old records of the SRS network and incorporated into the location algorithm. All new locations were derived using the HYPOELLIPSE computer program. Repeated trial runs revealed that the most stable locations were obtained when P and discernible S arrivals were used from stations within a 62-mi (100-km) radius of the computed hypocenter. HYPOELLIPSE provides a multiple crustal structure option for refinement of locations by allowing the use of varying velocity structure models for groups of stations according to their proximity to geologically differing areas of South Carolina. Varying velocity models have been developed using 20 years of seismic refraction surveys completed throughout South Carolina. A total of five velocity models covering the entire state of South Carolina were developed from these data. These five velocity models change from one physiographic province to another and have been applied to each recording station accordingly. Further refinement to reflect the structure of a buried Triassic basin (Dunbarton Basin) lying beneath two SRS stations has also been provided.

Relocation results are presented in Table 1.3.6-3 and plotted on Figure 1.3.6-3. The $'s represent old locations and #'s represent the new locations. Four events (26 July 1945, 15 November 1978, 16 January 1979, and 07 January 1992) have no # sign associated with them because their revised locations either plotted out of the 50-mi (80-km) radius (26 July 1945 and 07 January 1992), or upon closer inspection were discovered not to be real events at all (15 November 1978 and 16 January 1979). Consequently, these four events have been removed from consideration as reflected in Table 1.3.6-3. All relocations showed improvement in quality estimates. The revised locations show few, if any, changes between $'s and #'s. The depth estimate parameter returned by the HYPOELLIPSE on all relocated events remained less than 7.5 mi (12.1 km). However, no relocated event had a depth of less than 1.4 mi (2.3 km), where original estimates had some events with depths at less than 0.6 mi (1 km).

The largest felt event to have occurred within a 50-mi (80-km) radius of SRS is the August 8, 1993 (09:24 UCT, 5:24 a.m. EDST), Couchton earthquake near Aiken, South Carolina (approximately 40 mi [65 km] north of SRS). It was widely felt throughout the region in Williston, New Ellenton, and SRS. The MMI intensity for this event was estimated at IV-V with a duration magnitude of 3.2. No seismic alarms were triggered. The location of this event plotted on the flanks of a localized gravity low, indicating relation to Piedmont-type activity associated with the boundary of a buried intrusive rather than a large-scale regional feature.

1.3.6.1.3.1 Recorded Activity (Regional)

The distribution of eastern United States instrumentally located epicenters essentially coincides with pre-network, historical seismicity. That is, the pattern of historical activity, which is based on larger-magnitude, felt events, is reproduced in the pattern of smaller, instrumentally located events. A non-random spatial distribution of epicenters is noted with patterns that lie parallel as well as transverse to the northeasterly tectonic fabric of the Appalachians. Appreciable seismic activity is displayed trending along the Appalachian highlands (i.e., the Blue Ridge) with other broad trends of activity seen primarily in the Piedmont and Coastal Plain provinces of Virginia, South Carolina, and Georgia. These apparent trends led to a zonal interpretation of southeast regional seismicity that includes the Appalachian zone, Virginia zone, and the South Carolina-Georgia zone. A broader and simpler zonation concept has been developed that includes the dominant regional trend (along Appalachian highlands) and specific zones defined by areas of concentrated activity (see Figure 1.3.6-1).

Results obtained from network data within the South Carolina-SRS region identified the Piedmont and Coastal Plain physiographic provinces as two diffuse areas of seismic activity. Through these studies, the Coastal Plain was further divided into three distinct clusters of seismicity that include the Bowman Seismogenic Zone, the MPSSZ, and the Jedburg-Adams Run Seismogenic Zone. The most active zone is the MPSSZ, which is the only one to coincide with the meizoseismal area of the 1886 Charleston earthquake. (Refer to Section 1.3.6.2 for more details on this zone.) Earthquake activity within the Piedmont not associated with reservoir-induced activity can best be characterized by occasional small shallow events associated with strain release near small-scale faults, intrusives, and edges of metamorphic belts.

1.3.6.1.3.2 SRS Onsite Earthquake Activity

Three earthquakes of MMI III or less have occurred with epicentral locations within the boundaries of SRS. On June 9, 1985, an intensity III earthquake with a local duration magnitude of 2.6 occurred at SRS. Felt reports were more common at the western edge of the central portion of the SRS plant site. Figure 1.3.6-6 shows the resulting isoseismal intensity map, and Figure 1.3.6-7 shows a fault plane solution for this event. Another event occurred at SRS on August 5, 1988, with an MMI I-II and a local duration magnitude of 2.0. A survey of SRS personnel who were at the site during the 1988 earthquake indicated that it was not felt at SRS. Neither of these earthquakes triggered seismic alarms (set point 0.002g) at SRS facilities. These earthquakes were of similar magnitude and intensity as several recent events with epicenters southeast of SRS (Table 1.3.6-3).

On the evening of May 17, 1997, at 23:38:38.6 UTC (7:38 pm EDST) an MD ~ 2.3 (Duration Magnitude) earthquake occurred within the boundary of SRS. It was reported as being felt by workers in K Area and by Wackenhut guards at a nearby barricade. A strong motion accelerograph (SMA) located 3 mi (4.8 km) southeast of the epicenter at Gun Site 51 was not triggered by the event. The SMA located approximately 10 mi (16 km) north of the event in the seismic lab building 735-11A was not triggered. The closest instrument to the epicenter (Gun Site 51) is set at a trigger threshold of 0.3% of full scale where full scale is 2.0g (0.006g). The more distant lab SMA is set to trigger at a threshold of 0.1% of full scale where full scale is 1.0g (0.001g).

1.3.6.1.4 Seismic Networks

1.3.6.1.4.1 Local

As discussed above, a short-period seismic network was established at SRS in 1976 with the installation of three single-component vertical stations. In 1987, digital recording capability and a fourth three-component (one vertical and two horizontal) site were added to the network. Other short-period instrumentation has been added through the years to more completely cover the site with the total number of short-period stations currently at eight. In addition to the short-period network, a ten-station SMA network was more recently (1998, 1999) installed throughout the SRS complex.

1.3.6.1.4.2 DOE SMA Network

Ten new SMAs have been installed in selected DOE structures at foundation level, other selected elevations, and in the free-field. In the event of an earthquake of sufficient size to trigger the installed instrumentation, free-field instrumentation data can be used by DOE to compare measured response to the design input motion for the structures and to determine whether the operating basis earthquake has been exceeded. The instruments located at the foundation level and at elevation in the structures can be used to compare measured response to the design input motion for equipment and piping and can be used in long-term evaluations. In addition, foundation-level instrumentation can provide data on the actual seismic input to the mission-critical structures and can be used to quantify differences between the vibratory ground motion at the free-field and at the foundation level. SMA instrumentation is set to trigger at 2.0% full scale with full scale being 1g (i.e., trigger set at 0.02g). Figure 1.3.6-8 shows the current station configuration with specific instrument locations. Numbered locations on the figure correspond to the numbers in parentheses appearing just before the location description below:

A Area	(1) One free-field SMA is located on the floor of the seismic laboratory.
F Area	(2) One SMA is located in close proximity to the top of tanks in the F-Area Tank Farm. (3) One SMA is located at foundation level in F Canyon.
H Area	(4,5) Two SMAs are located near the H-Area Tank Farm: one at the top of the tanks and one at the bottom. (6,7) Two SMAs are located at H Canyon: one at elevation on the roof and one at the foundation level. (8) One SMA is located in the Replacement Tritium Facility (RTF) at foundation level.
K Area	(9) One SMA is located in K-Reactor building at foundation level.
L Area	(10) One SMA is located in L-Reactor building at foundation level.
S Area	(11) One SMA is located at the Defense Waste Processing Facility (DWPF).
Other	Two additional SMAs are located in remote field locations: (12) PAR Pond (13) Gun Site 51

1.3.6.1.4.3 DOE Short-Period Seismic Monitoring Network (1991-Present)

From 1991 to the present, the following short-period instrumentation has been operated and maintained onsite (see Figure 1.3.6-4):

- Vertical short-period digital seismic array, which consists of geophones (sensors) placed at different levels within a deep borehole located near the center of SRS to monitor effects of soil column for engineering analysis and design.

- Seven-station continuous-recording short-period telemetered seismic monitoring network for location and depth determination of locally occurring seismic activity.

1.3.6.1.4.4 Regional

To address the regional seismic issues within 150 to 200 mi (241 to 322 km) of SRS, the University of South Carolina operates and maintains the South Carolina Seismic Network, which includes regional statewide stations located east of SRS, as well as a small network of stations surrounding the most significant seismic source zone affecting SRS (the Charleston, South Carolina, region). Figure 1.3.6-9 depicts the station locations for SRS and the surrounding region. This program serves to complement current ongoing local SRS seismic data and studies by providing access to regional data and independent sources of data and expertise.

1.3.6.2 Relationship of Geologic Structure to Seismic Sources in the General Site Region

Within the southeastern United States, seismicity generally occurs in distinct zones superimposed on a regional background of very low level seismicity. These distinct zones of epicentral distribution are both parallel and oblique to the general northeastern trend of the tectonic structures in the region. As a general result, the relationship between the observed tectonic structures and seismic activity in the region remains unknown. Therefore, in most instances, the seismic sources are inferred rather than demonstrated by strong correlation with geologic structure. This diffuse characteristic of foci suggests the presence of multiple rather than specific seismogenic structural elements such as small-scale faults, intrusive bodies, and edges of metamorphic belts.

In this region, only about 65% of the instrumentally recorded earthquakes have focal depth determined, and only then with modest accuracy of about +/- 3 mi (+/- 4.8 km). About 90% of these earthquakes occur above a depth of 11 mi (17.7 km), and this depth defines the thickness of the brittle seismogenic crust. In the SRS region, the foci peak at about 3 mi (4.8 km) depth, although there is a smaller peak at about 5 mi (8 km).

For this discussion, a seismic zone is defined to extend from the Brevard zone in northwest South Carolina to just northwest of Charleston, South Carolina, where another seismic zone has been defined. The length of the zone is about 250 mi (400 km), and the width is 93 mi (150 km) on each side of the Savannah River. This places SRS in about the center of the zone and includes the COCORP seismic reflection lines in Georgia.

SRS seismic reflection data reprocessed by Virginia Polytechnical Institute present a remarkably high-resolution image of the crust from within 65.6 ft (20 m) of the surface to the Moho. The upper crust is highly reflective and is dominated by southeast dipping bands of laminar reflective packages that are correlatable across SRS. Two of the most prominent of these packages appear to correspond to reflections identified in COCORP lines 5 and 8 in Georgia as the Augusta fault and a mid-crustal detachment. The midcrustal detachment at SRS is a discrete mappable southeastern dipping reflection that occurs at 8.7 to 13.7 mi (14 to 22 km) depth. The Augusta fault is denoted by a distinct laminar southeast dipping reflector at 2.2 to 7.4 mi (3.6 to 12 km) depth (see Figure 1.3.6-10). In the southeastern portion of SRS, reflections from deformed

Triassic-Jurassic strata are evident. These reflections are truncated by a complex southeast dipping package of reflections that may mark the detachment along which the Dunbarton basin formed.

The quality of the reflection seismic data outside of SRS is not as good except for the ADCOH data at the north-northwestern end of the Savannah River Corridor and the COCORP lines 1, 5, and 8 obtained on the Georgia side on the Savannah River. The ADCOH data clearly imaged highly reflective strata of lower Paleozoic age beneath the Blue Ridge allochthon. This interpretation now appears to be generally accepted. A similar seismic signature has also been imaged on COCORP line 5, suggesting that the lower Paleozoic platform rock extends southeastward at least as far as COCORP line 5. If these interpretations are correct, then the master decollement must lie above the highly reflective shelf strata.

Studies of the seismotectonics in central Virginia have shown a correlation between the distribution of hypocenters and seismic reflectors. They suggest that the earthquake activity might be associated with reactivation along existing faults above a major decollement. The seismic reflection data in the Savannah River Corridor also suggest that not only is the seismicity similar to that in central Virginia, but it may also be related to the seismic reflection data in a similar manner. That is, the seismicity is related to reactivation of existing faults above major detachments (Blue Ridge master decollement and August fault), but in general, does not penetrate below the midcrustal reflections until one approaches the East Tennessee seismic zone at the northwestern end of the corridor.

Although there are uncertainties in the determination of hypocentral depths, the earthquakes in the zone do appear to be localized above what is interpreted to be lower Paleozoic platform rock, which is separated by the master decollement from the overlying allochthon. It is reasonable to suggest that the earthquakes have been localized in the more brittle crystalline allochthon rather than in the more ductile underlying Paleozoic platform shelf strata. Indeed, this is generally the case for all of the seismic zones in the eastern United States. Thus, there does appear to be an association of the seismicity with pre-existing structure in the upper 7.5 mi (12 km) of the brittle crust, which forms the seismogenic zone. This is important in that, for earthquakes with a moment magnitude (Mw) greater than 5.5, the main shock usually occurs near the base of the seismogenic zone. This may then represent the largest earthquakes that possibly could occur in the SRS region due to the limits on size created by the depth of the seismogenic zone.

1.3.6.3 Development of SRS Design Basis Earthquake

This section summarizes the phased development of the seismic criteria for SRS facilities. Probabilistic hazard, deterministic ground motion prediction methodologies, and the DBE history for SRS are described. The summary of the evolution of the SRS design basis provides the necessary background for facility construction that spans four decades. This section also describes DOE seismic criteria. Ground motion prediction methodologies are described in Section 1.3.6.4. Current design guidance is discussed in Section 1.3.6.5.

For engineering design of earthquake-resistant structures, empirically derived seismic response spectra are most commonly used to characterize ground motion as a function of frequency. These motions provide the input parameters used in the analysis of structural response and/or geotechnical evaluation. Response spectra are described in terms of oscillator damping, amplitude, and frequency and are defined as the maximum earthquake response of a suite of damped single degree-of-freedom oscillators. The response spectra are related to earthquake source parameters, the travel path of the seismic waves, and local site conditions. Over the last two decades, SRS response spectra have evolved from the use of a single scaled record of a western United States earthquake to a composite spectrum that may represent the response of more than one earthquake. In the latter approach, controlling DBEs represent a suite of earthquake magnitude and distance pairs that provide the maximum oscillator response in discrete frequency bands. The basis for controlling earthquakes is derived from detailed geologic and seismologic investigations conducted in accordance with 10 CFR Part 100 Appendix A. This approach is typically labeled the "deterministic" approach. This approach does not explicitly incorporate the rate of seismicity or the uncertainty in earthquake source parameters and ground motion.

An alternative to the deterministic approach is the Probabilistic Seismic Hazards Assessment (PSHA). The PSHA incorporates the source zone definition and ground motion prediction assessments required for the deterministic approach, but also considers the estimated rates of occurrence of earthquakes and explicitly incorporates the uncertainties in all parameters. This approach predicts the probability of exceeding a particular ground motion value at a location during a specified period of time. This approach is essential for hazard mitigation of spatially distributed facilities having different risk factors. The current DOE criteria used for SRS facilities are probabilistic-based.

For SRS, design spectral shapes are employed for earthquakes of different magnitudes and travel paths. The following principal spectra have been developed for SRS using deterministic methodologies or combinations of deterministic methodologies:

- Housner, *Earthquake Criteria for the Savannah River Plant* (Housner 1968)
- Blume, *Update of Seismic Criteria for the Savannah River Plant* (URS/Blume 1982)
- Geomatrix, *Ground Motion Following Selection of SRS Design Basis Earthquake and Associated Deterministic Approach* (Geomatrix Consultants 1991)
- WSRC, *Update of H-Area Seismic Design Basis* (Lee 1994)
- WSRC, *Savannah River Site Seismic Response Analysis and Design Basis Guidelines* (Lee et al. 1997)
- WSRC, *Soil Surface Seismic Hazard and Design Basis Guidelines for Performance Category 1 & 2 SRS Facilities* (Lee 1998).

Each of these portrays a step in the evolution of the understanding of the seismic process. The scientific and technical basis used in developing the DBE is described herein.

The Housner spectrum was the response of a single record, the Taft record, from the 1952 Tehachippi earthquake. In contrast, the Blume study developed a composite free-field spectrum that enveloped three postulated events: (1) a random local earthquake (<15 mi [<25 km]), (2) a large earthquake originating near Bowman, South Carolina, and (3) a repeat of the 1886 Charleston, South Carolina, earthquake. Although different methodologies were used to develop response spectra, the Geomatrix study used the same three earthquake sources except that the 1886 Charleston earthquake was increased slightly in magnitude and moved a few tens of kilometers closer to the site. In both the Geomatrix and Blume investigations, the postulated Bowman earthquake did not control motions at any spectral frequency; consequently, only two controlling events were modeled: (1) the random local earthquake, and (2) the larger, more distant, Charleston event.

The Housner and Blume spectra were based on western United States strong motion data because strong motion data were unavailable at that time in the eastern United States for earthquake magnitudes and distances necessary for design. Since the Blume study was conducted, ground motion studies have shown that seismic path and site properties are very different between the eastern United States and western United States. Current analytical approaches directly estimate spectra by using South East U.S. Coastal Plain conditions to model path effects on wave propagation. Current design basis spectra are based on a hybrid of deterministic and probabilistic approaches.

1.3.6.3.1 Criteria for DOE Facilities

Seismic design criteria for nonreactor DOE facilities are contained in DOE Order 420.1, DOE-STD-1020-94, and DOE-STD-1024-92 (DOE 1995, 1994, 1996a). Additionally, site characterization criteria can be found in DOE STD-1022-94 (DOE 1996c).

Earlier estimates of ground motion for SRS critical facilities have generally adopted NRC regulatory guidance provided in 10 CFR Part 100, Appendix A. This deterministic guidance was applied, for example, at K Reactor. However, the more recent seismic evaluations have employed the probabilistic guidance contained in DOE-STD-1024-92 and DOE-STD-1023-95 (DOE 1996a, 1996b).

DOE Order 420.1 provides requirements for mitigating natural phenomena hazards that include seismic, wind, flood, and lightning (DOE 1995). DOE-STD-1020-94 defines the performance goals for seismic, wind, tornado, and flood hazards (DOE 1994).

DOE-STD-1021-93 provides guidelines for selecting performance categories of SSCs, for the purpose of NPH design and evaluation (DOE 1996d). This standard recommends general procedures for consistent application of DOE's performance categorization guidelines.

DOE-STD-1020-94 and DOE-STD-1024-92 require the use of median input response spectra that are determined from site-specific geotechnical studies and anchored to peak ground accelerations (PGAs) determined for the appropriate facility-use annual rate of exceedance (DOE 1994, 1996a). Guidance regarding the specific characterization of seismic hazard is found in the Systematic Evaluation Program guidance and DOE-STD-1022-94 (DOE 1996c).

DOE-STD-1024-92 was an interim standard that requires deterministic and probabilistic methodologies be used for hazard evaluation and was superseded by DOE-STD-1023-95 (DOE 1996a, 1996b). The guidelines for probabilistic hazard analyses are as follows: (1) sites can use a combined Electric Power Research Institute (EPRI) and Lawrence Livermore National Laboratory (LLNL) result if applicable, or (2) sites can complete a new estimate using site-specific data including definition of source zones, earthquake recurrence rates, ground motion attenuation, and computational methodologies that are spelled out in the Systematic Evaluation Program.

DOE-STD-1023-95 provides guidelines for developing site-specific probabilistic seismic hazard assessments and criteria for determining ground motion parameters for the design earthquakes (DOE 1996b). It also provides criteria for determination of design response spectra. Five performance categories are specified, from performance category 0 (PC-0) for SSCs that require no hazard evaluation, to design of PC-4, a desired performance level comparable to commercial nuclear power plants. These criteria address weaknesses in prior guidance by specifying Uniform Hazard Spectrum (UHS) controlling frequencies, requiring a site-specific spectral shape and a historic earthquake check, to ensure that the DBE contains sufficient breadth to accommodate anticipated motions from historic earthquakes above Mw 6.

The fundamental elements of the criteria for DOE moderate hazard (PC-3) and high hazard (PC-4) facilities are as follows:

1. A PSHA is conducted for the site (or use an existing PSHA that is less than 10 years old).
2. A target DBE response spectrum is defined by the mean UHS.
3. Mean UHS shapes are checked by median site-specific spectral shapes, which are derived from de-aggregated PSHA earthquake source parameters. The median site-specific spectral shapes are scaled to the UHS at two specific frequencies (average 1 to 2.5 and 5 to 10 Hz).
4. Estimated site-specific ground motions from historical earthquakes (significant felt or instrumental with Mw > 6) are developed using best-estimate magnitude and distance.
5. Spectral shapes are adjusted until DBE response spectra have a smooth site-specific shape.

Recently, NEHRP-97 (BSSC [Building Seismic Safety Council] 1997) criteria have been adopted by WSRC and DOE for evaluation of spectra for PC-1 and PC-2 facilities and structures (Lee 1998). DOE-STD-1023-95 (DOE 1996b) allows the use of building codes and/or alternate design criteria for DOE PC-1 and PC-2 design. The NEHRP design criteria are defined as two-thirds of the maximum considered earthquake ground motion (i.e., two-thirds of the 2,500-year UHS).

1.3.6.3.2 Historical Perspective on Design Basis Earthquakes at the Savannah River Site

Because maximum potential causative fault structures within the Coastal Plain, Piedmont, and Blue Ridge provinces are not clearly delineated by lower-level seismicity or geomorphic features, past guidance prescribes the use of an assumed local earthquake. The magnitude/intensity is conservatively assumed to be a repeat of the largest historic event in a given tectonic province located at that province's closest approach to the site. Application of this guidance has resulted in the definition of two controlling earthquakes for the seismic hazard at SRS. One earthquake is a local event comparable in magnitude and intensity to the Union County earthquake of 1913 but occurring within a distance of about 15 mi (25 km) from the site. The other controlling earthquake represents a potential repeat of the 1886 Charleston earthquake. Selection of these controlling earthquakes for design basis spectra has not changed significantly in over 20 years. However, the assumed maximum earthquake moment and magnitude estimates have increased in the more recent assessments of the 1886 Charleston earthquake. In addition, the assumed distance to a repeat of the 1886 Charleston-type earthquake has slightly decreased.

Until the late 1980s, investigations performed for the NRC focused on the uniqueness of the location of the Charleston earthquake, due to a lack of knowledge of a positive causative structure at Charleston. At issue was the possibility of a rupture on any one of the numerous northeast-trending basement faults located throughout the eastern seaboard. Further, there were no obvious geomorphic expressions that might suggest large repeated faulting.

Evidence that defines the Charleston Seismogenic Zone is as follows:

- The detailed analyses of isoseismals following the 1886 Charleston earthquake
- Instrumental locations and focal mechanisms of seismicity defining the 31-mi (50-km) long Woodstock fault lineament, which closely parallels the north-northeast trending isoseismals
- The remote-sensed 8.2-ft (2.5-m) high, 15.5-mi (25-km) long lineament that also parallels the Woodstock fault.

Paleoliquefaction investigations along the coasts of Georgia, North Carolina, and South Carolina have identified and dated multiple episodes of paleoliquefaction that have constrained the latitude of the episodes. Crater frequency and width are greatest in the Charleston area and decrease in frequency and width with increased distance along the coast away from Charleston. This evidence led the NRC in 1992 to its position that a repeat of the Charleston earthquake was assumed to be restricted to the Charleston, Middleton Place region. NRC guidance for the nearby Vogtle Electric Generating Plant (VEGP) therefore has been based on an assumed recurrence of the 1886 Charleston earthquake in the Summerville-Charleston area. Sporadic and apparently random low-level seismicity is characteristic of the Coastal Plain and Piedmont geologic provinces (excepting clusters of seismicity in Bowman and Middleton Place). Regulatory guidance has prescribed a design basis local event to occur at a random location within a specified radius of the site.

The following sections contain, for historical reasons, brief summaries of the important deterministic and probabilistic seismic hazard investigations that have been conducted at or applied to various facilities at SRS.

1.3.6.3.2.1 Housner

The earliest spectra used at SRS were developed by Housner who used a 5% damped response from the 1952 Taft earthquake (Housner 1968). For a repeat of the Charleston earthquake, Housner predicted 0.1g PGA at SRS and conservatively recommended 0.2g PGA for the DBE. These spectra were used in an early evaluation of the seismic adequacy of production reactors at the site but are no longer considered acceptable for design basis analysis.

1.3.6.3.2.2 Blume

Recommended site acceleration and spectra in the Blume analysis were based on conservative assumptions for the occurrence of specific earthquakes (URS/Blume 1982). The anticipated ground motions from those events were developed from recorded earthquakes and synthetic seismograms for those postulated events. A probabilistic seismic hazard evaluation was also performed. Two hypothetical earthquakes consistent in size with earthquakes that have occurred in similar geologic environments were found to control SRS spectra and peak ground motion: (1) a hypothesized site MM VII local earthquake, causing an estimated site PGA of 0.1g; and (2) a hypothetical intensity X earthquake (1886 Charleston-type), occurring at a distance of 90 mi (145 km) and causing an estimated site PGA of <0.1g. For added conservatism, the site PGA was increased to 0.2g, which corresponded to a site intensity of VIII (see Figure 1.3.6-2). The PSHA indicated that the mean annual rate of exceedance of 2×10^{-4}, corresponding to 0.2g, was comparable to those probabilistic hazard studies developed for nearby nuclear power plants.

In the Blume study, the following three seismogenic source regions were considered for ground motion assessment:

- Appalachian Mountains including the Piedmont and Blue Ridge geologic provinces assessed at a maximum intensity VIII.
- Atlantic Coastal Plain, including SRS, assessed at a maximum intensity VII.
- The Charleston Seismogenic Zone with an epicentral intensity of X. A hypothetical Charleston event was also assumed to occur at Bowman for the purposes of estimating the distance for the attenuation of ground motion.

The length of the 1886 Charleston Seismogenic Zone was estimated as 31 mi (50 km) based on the elongation of the highest intensity isoseismal and on the length and location of the inferred Woodstock fault as determined by instrumental location and mechanisms of earthquakes. A displacement of 78.7 in (200 cm) was estimated for the Charleston event based on the source dimension and the seismic moment. The source mechanism was assumed to be similar to the mechanisms recorded along the Woodstock fault: steeply dipping right lateral strike-slip fault oriented N10°E.

The estimated PGAs for postulated maximum events were based on the following:

- A local earthquake of MMI VII: a maximum credible earthquake for the Atlantic Coastal Plain
- A Fall Line event, MMI VIII with distance > 28 mi (45 km): a maximum credible earthquake for the Piedmont
- A Middleton Place event of MMI X: a repeat of the Charleston 1886 earthquake
- A Bowman, MMI X: a postulated and considered extremely unlikely occurrence of a 1886 type-event at closest credible distance of 59 mi (95 km).

Blume applied a confidence margin of one intensity unit to the estimates in Table 1.3.6-4, resulting in a site intensity of VIII with a corresponding doubling of the estimated PGA (to 0.2g).

Using the PHA, Blume noted that a doubling of the PGA results in an approximate order of magnitude smaller probability of exceedance.

Local and distant earthquake response spectral shapes were derived from statistical analysis of primarily western United States (western) data. The recommended response spectra were computed from the envelope of the mean spectral shapes (see Figure 1.3.6-11).

1.3.6.3.2.3 Geomatrix (K Reactor)

In a manner similar to Blume, Geomatrix performed a deterministic analysis following Section 2.5.2 of NUREG-0800 for K Reactor (Geomatrix Consultants, Inc. 1991). The resulting spectra were developed for a distant Charleston source and a local source. The Charleston source was modeled for Mw 7.5 using the Random Vibration Theory (RVT) model. Site-specific soil data were used to address the impact of local conditions of the spectral content. The local source assumed an Mw 5 and used empirical western United States deep soil strong motion data corrected for eastern United States soil and rock conditions. The 5% damped spectra for the two hypothetical controlling earthquakes are illustrated in Figure 1.3.6-11.

The primary uncertainty related to the 1886 Charleston earthquake moment magnitude estimate was the interpretation of intensity, which was derived from reported damage patterns. The fault rupture width was estimated to be 12.4 mi (20 km) based on a range of deepest Coastal Plain hypocenters. The rupture length was determined from regressions of worldwide M_o vs. rupture area. From the rupture dimensions and moment, Geomatrix estimated a stress drop of 65 bars and an average displacement of 157 in (400 cm).

The Bowman seismicity zone, located in the Coastal Plain province, consists of M 3.5-4.0 events occurring along a northwest trend from Charleston. Because of the timing and mechanisms of events, they are not believed to be associated with the Charleston Seismogenic Zone. The largest historical earthquake in the Piedmont Province was the 1913 Union County earthquake having an epicentral intensity of VI-VII. Based on Johnston isoseismal areas, that earthquake was estimated to be Mw 4.5. The largest Appalachian province earthquake was the 1875 Central Virginia event of MMI VII and Mw = 4.8. These earthquakes suggest Mw_{max} of 5.0 for Bowman, but because it was part of a diffuse north-west trend, Geomatrix used 6.0 for conservatism. The Bowman earthquake did not control site motions (similarly to the Blume study) and consequently was not used in specification of design basis motions.

For the local earthquake, the occurrence of a random earthquake within 15.5 mi (25 km) of K Reactor was assumed. With the largest site vicinity events limited to magnitude range 2 to 3, guidance suggests using largest historical events in the Piedmont Province: Mw_{max} = 5.0.

Geomatrix developed 5% damped response of the horizontal component from an Mw 7.5, 150 bar stress drop Charleston-type earthquake using the parameters described above (see Figure 1.3.6-11). The vertical component of motion was estimated to be half the horizontal. Table 1.3.6-5 summarizes the source parameters and predicted motions from these earthquakes.

Statistics for the Geomatrix local earthquake were selected using strong motion records from earthquakes of Mw 5.0 ± 0.5 within 15.5 mi (25 km) of the epicenter. The Geomatrix local earthquake spectral shape was scaled in accordance with DOE-STD-1024-92 guidance (DOE 1996a).

1.3.6.3.3 Evaluation Basis Earthquake Spectra

For the 1993 liquefaction studies at the RTF, the design basis envelope spectra contained in the Blume report were not recommended because the spectra were not representative of a specific earthquake. Seismic hazard results show that the site can be characterized by local events, with R <25 km, controlling the PGA. Larger events, at some distance from the site, controlled peak ground velocity at SRS. These results compared favorably with the deterministic analyses performed for the site by Blume and Geomatrix.

The controlling earthquakes used in the liquefaction study at the RTF were selected to be consistent with the DOE probabilistic acceptance criteria. A spectral shape was taken from the local event spectra developed for K Reactor. The distant event spectra were recommended unscaled (see Figure 1.3.6-11). The results were then compared to the past deterministic study of Blume and the disaggregated LLNL and EPRI hazard analyses. Induced stresses were calculated for the liquefaction analysis based on the two controlling earthquakes. Separate analysis is warranted based on the difference in shape of the two spectra.

The RTF spectra were later named the evaluation basis earthquake and used to support initial geotechnical evaluations for the H-Area In-Tank Precipitation Facility (ITP) and H-Area Tank Farms. The evaluation basis earthquake spectra were used until site-specific spectra could be developed to judge adequacy. The evaluation basis earthquake spectra, which account for local and distant earthquakes, were consistent with DOE criteria and were used for the initial geotechnical evaluation.

1.3.6.3.4 WSRC (H-Area Spectrum)

Following initial site-specific evaluations performed for the ITP and H Area, a revised spectrum (84^{th} percentile deterministic spectrum) was developed and recommended for structural engineering and geotechnical analysis of facilities in H Area. The geotechnical analysis utilized the basement results in a convolution analysis, and the structural engineering groups developed an envelope for use in analysis of SSCs. The resulting structural design spectrum envelope is shown in Figure 1.3.6-12.

The fundamental change was to the distant earthquake component. The parameters used to develop a 50^{th} and 84^{th} percentile spectrum were site-specific soil and revised stress drop for a Charleston earthquake.

EPRI and LLNL hazard spectra were used to estimate the probability of exceedance of the spectra. The local event spectrum was unchanged from the evaluation basis earthquake. The resulting local and distant spectra were then enveloped into a surface design spectrum (Figure 1.3.6-12).

1.3.6.3.5 WSRC (PC-3 and PC-4 Sitewide Design Spectra)

The sitewide design spectra fully implement DOE-STD-1023-95 (DOE 1996b). DOE-STD-1023-95 specifies a broadened mean-based UHS representing a specified annual probability of exceedance (for an SSC performance category) and a historical earthquake deterministic spectrum that ensures breadth of the UHS. For SRS, the deterministic spectrum is represented by a repeat of the 1886 Charleston earthquake. The development of the SRS design basis spectra uses a statistical methodology to verify that a mean-based response is achieved at the soil free surface.

The design spectra were intended for simple response analysis of SSCs and are not appropriate for soil-structure interaction analysis or geotechnical assessments. The design basis spectra for PC-3 and PC-4 are given in Figures 1.3.6-13 and 1.3.6-14, respectively.

The EPRI and LLNL bedrock level uniform hazard spectra were averaged and broadened in accordance with DOE-STD-1023-95 (DOE 1996b). Available SRS soil data were used to parameterize the soil shear-wave velocity profile. The parameterization was used to establish statistics on site response for ranges of soil column thickness present at SRS. The mean soil UHS was obtained by scaling the bedrock UHS by the ground motion dependent mean site amplification functions.

The soil data used to develop the sitewide spectra incorporate the available SRS velocity and dynamic property database available to about mid-1996. The spectra are based on soil properties and stratigraphy from specific locations at SRS and are parameterized to represent the variability in measured properties. Because of the potential for variation of soil properties in excess of what have been measured at SRS, the design basis spectra are issued as "committed" for DOE facilities at SRS. The open item is the soil column variability used in the calculations. The soil parameters for the MFFF site have been checked for consistency with the data parameterized in the study, and the spectra have been confirmed to be applicable to the MFFF.

DOE PC-3 and PC-4 design spectra are compared to the SRS interim spectrum and the Blume envelope spectrum (Figure 1.3.6-15). There is broad general agreement between the PC-3 and interim spectral shape. The SRS interim spectrum shape is significantly more conservative in the frequency range of 0.5 to 2.0 Hz compared to the PC-3 spectrum because the interim shape enveloped the 84th percentile Charleston deterministic spectrum rather than the 50th percentile as required by DOE-STD-1023-95 (DOE 1996b). Comparisons of the Blume 0.20g anchored spectrum to the PC-3 design spectrum indicate significant shape differences. The Blume spectrum was derived from deep soil recordings of western U.S. earthquakes and is not representative of eastern United States spectral shapes. The spectra show a generally more broadened shape as compared to the Blume spectra (see Figure 1.3.6-15). Low frequencies are enhanced with respect to Blume because the Blume spectra do not contain the fundamental site resonance (about 0.6 Hz). High frequencies are also enhanced with respect to Blume because of the difference in eastern and western United States attenuative properties. Both the PC-3 spectrum and the Blume spectrum have a dynamic amplification of about 2.7 at 3 Hz. The significantly larger Blume PGA scaling factor causes the excess (as compared to the design basis spectrum) spectral values at the mid-range.

1.3.6.3.6 WSRC (PC-1 and PC-2 Sitewide Design Spectra)

Design spectra guidelines for DOE PC-1 and PC-2 facilities are reported by Lee (1998). The DOE PC-1 and PC-2 design spectra were derived using DOE-STD-1023-95 guidelines and NEHRP-97 (BSSC 1997) design criteria and account for the wide range in SRS material properties and geometries including soil shear-wave velocities, uncertainty or range in soil column thickness, and type of basement material. Additional design guidance is contained in the current revision of WSRC Engineering Standard 01060 (WSRC 1999a).

1.3.6.3.6.1 SRS-Specific Probabilistic Seismic Hazard Assessments

An SRS-specific PSHA was developed using bedrock outcrop EPRI and LLNL hazard and SRS site properties including soil column thickness, soil and bedrock shear-wave velocity, and dynamic properties. The *MOX Fuel Fabrication Facility Site Geotechnical Report* (DCS 2001) contains a detailed presentation of the site investigations that have been conducted and the results of site-specific analyses. Section 3.4 of DCS 2001 also demonstrates the applicability of the SRS site generic PSHA to the MFFF site. Section 5.0 of DCS 2001 presents subsurface conditions at the MFFF site and demonstrates that they are consistent with subsurface conditions that exist at the adjacent F Area at SRS. Section 6.2 of DCS 2001 presents dynamic properties for the subsurface soils and the one-dimensional free-field response analyses for the MFFF site. Consequently, another PSHA specific to the MFFF site is not required.

The bedrock seismic hazard evaluations used for the SRS-specific soil surface hazard were the EPRI and LLNL results for bedrock for SRS and vicinity. These evaluations did not revise or confirm in any way the experts' evaluations of activity rates, seismic source zonation, or the decay of ground motion with distance used in the LLNL or EPRI seismic hazard assessments. The analysis results in an SRS-specific hazard evaluation for a soil site by continuing the hazard from bedrock to the soil surface using detailed soil response functions. Earthquake magnitude and ground motion level dependence of the site response are accommodated by applying site response functions consistent with the distribution of earthquake magnitude and ground motion levels obtained from disaggregating the bedrock uniform hazard spectrum.

Frequency and ground motion level dependent soil amplification functions developed in WSRC-TR-97-0085 (Lee et al. 1997) were used to account for the observed variations in properties throughout SRS, including soil column thickness, stratigraphy, shear-wave velocity, and material dynamic properties, as well as basement properties. Soil amplification functions (frequency-dependent ratio of soil response to bedrock input) were derived in WSRC-TR-97-0085 (Lee et al. 1997) by performing a statistical analysis of the response of bedrock spectra through realizable soil columns bounded by the observed variations in soil-column properties over SRS. Ground motion level-dependent distributions of soil amplification functions were derived for each of six soil categories: three on crystalline basement and three on Triassic basement. Those soil amplification function distributions were used to compute soil surface hazard.

The methodology used to compute soil surface hazard is to difference the bedrock hazard disaggregation for a suite of bedrock motions and sum the probability of exceedance of surface motions using the appropriate magnitude and ground motion level-dependent soil/rock transfer functions. The approach yields soil surface hazard that would be obtained from correctly applying local site soil transfer functions to the ground motion attenuation model used in a PSHA. The analysis is repeated at the oscillator frequencies available in the bedrock hazard disaggregation and for each soil column thickness and bedrock type. The envelope of the hazard curves is taken from the soil and bedrock categories. The curves represent hazard at the top of the soil column for oscillator frequencies of 1, 2.5, 5, and 10 Hz (Figure 1.3.6-16) in terms of spectral velocity. Figure 1.3.6-24 presents the same hazard information in terms of spectral accelerations at the soil surface.

High and low probability extrapolations of bedrock hazard curves were made to meet the ranges of probability required for engineering risk assessments (annual probabilities as low as 10^{-7} were considered). Soil surface hazard results computed in the range of bedrock hazard extrapolations are considered more uncertain. Consequently, computed ground surface hazard curves for annual probabilities greater than about 10^{-2} or less than about 10^{-6} should be used with caution. These results were computed using a 3-σ truncation on the ground motion probability of exceedance and a lower bound of 0.5 on the soil amplification function.

PSHAs developed for SRS prior to the LLNL and EPRI studies, as well as the hazard derived from the combination of the original EPRI and LLNL soil surface hazard, were derived for PGA only and did not use SRS-specific soils data. Historically, engineering applications and earthquake design used PSHAs that were PGA-based, a practice that has diminished for the last 20 years because of improved interpretations from broader-band seismic recording and the better understanding of the broad-band nature of seismic hazard. The engineering use of PGA PSHAs is neither recommended nor consistent with DOE-STD-1023-95 (DOE 1996b).

1.3.6.4 Ground Motion Prediction Methodologies

This section briefly describes the methodology for current ground motion prediction and earthquake source, path, and site assumptions used for H Area, the most recent DBE work conducted for SRS.

1.3.6.4.1 Random Vibration Theory (RVT) Modeling

To model ground motion, an RVT model (also called Band Limited White Noise) is used to estimate ground motion for the distant Charleston-type event. The RVT model is widely accepted and, with proper parameterization, is found to predict ground motion as successfully as empirically derived relationships. Because of the model's simplicity, computational speed, ability to parameterize source, geometrical spreading, crustal attenuation, and site response, it is ideally suited to quantifying ground motion. The RVT methodology appears to be well suited in geologic environments where empirical strong motion data may not exist in the earthquake magnitude and distance ranges of interest. Nonlinear wave propagation within the soil column is accounted for by using a computer modeling program, such as SHAKE, or equivalent approach.

1.3.6.4.2 Earthquake Source Parameters

This section discusses the earthquake source parameter uncertainty affecting ground motion prediction for SRS. Figure 1.3.6-2 shows a distance from the SRS site center to the 1886 Charleston MMI X isoseismal contour of approximately 74.5 mi (120 km). The SRS center to the southern end of the Woodstock fault is approximately 80.8 mi (130 km). The center of SRS to the center of the 1886 MMI X isoseismal, close to Middleton Place and central to the isoseismals, measures approximately 90 mi (145 km). URS/Blume used 145 km as the distance from the SRS center to the 1886 Charleston earthquake epicenter (URS/Blume 1982). Current ground motion studies analyze a recurrence of the 1886 event with a distance of 74.5 mi (120 km). For estimates of median ground motions for a recurrence of the 1886 earthquake, a source distance of 74.5 mi (120 km) is conservative since the center of the isoseismal zone is at a distance of approximately 90 mi (145 km).

For simplicity, the RVT models of ground motion assume a point source. The effects of focal depth and crustal structure on predicted ground motion are described by Lee (1994).

The distance and stress drop effects on rock motion predictions for a repeat of the Charleston Mw 7.5 event were described by Lee (1994). The 100-150 bar range in stress drop is a probable range for the median value of an eastern United States earthquake. Somerville et al. (1987) found a value of 100 bars as the median stress drop for eastern United States earthquakes. The EPRI report *1993 Guidelines for Determining Design Basis Ground Motions* (EPRI 1993) estimated a value of 120 bars as a median for stress drop, from data with reported stress drops in the range of 20 to 600 bars.

Prior ground motion studies for SRS have used expected or median stress drops of 100 to 150 bars for a Charleston-type event. Peak ground motion is sensitive to the selection of stress drop.

The 1886 isoseismal data are consistent with ground motion models with a slightly reduced earthquake moment magnitude of Mw 7.3, but with a corresponding higher stress drop. The favored median model uses a Mw 7.3 at 74.5 mi (120 km) and a stress drop of 150 bars.

1.3.6.4.3 Bedrock and Crustal Path Properties

Ground motion estimates used a modified Herrmann crustal model developed from surface wave dispersion from Bowman, South Carolina, to Atlanta, Georgia (Table 1.3.6-6).

For geometrical attenuation, a plane-layered crustal model approximation is used that accounts for the post-critical reflection. The effect of this approximation is to decrease the attenuating loss between about 49.7 to 74.5 mi (80 to 120 km). Using a point source and the local crustal structure for the Charleston event, the attenuation model predictions were found sensitive to source depth and source distance.

For development of the RVT rock spectra, anelastic attenuation is accounted for in two ways: (1) the crustal path operator Q that is frequency-dependent; and (2) the site-dependent factor Kappa, related to Q by H/(Vs*Qs). Where Qs is the average quality factor over a several kilometer range of the near surface rock. The preferred Q model for these investigations is the EPRI report, *1993 Guidelines for Determining Design Basis Ground Motions* (EPRI 1993).

The ranges of the rock site attenuation operator Kappa are estimated to be 0.010 to 0.004 seconds with a median of 0.006 seconds (EPRI 1993). RVT calculations for the SRS ground motion predictions use this median value of 0.006 seconds for Kappa.

For SRS ground motion predictions, bedrock properties underlying most of the SRS facilities are assumed uniform with a Vs of approximately 11,500 fps (3.4 km/sec). For facilities situated above the Triassic rift basin (Dunbarton basin), filled with 1.8 mi (3 km) of sedimentary rock, a Vs estimated to be 8,000 fps (2.4 km/sec) is used. This basin is surrounded by crystalline rock. For a first approximation to the ground motion effects of the basin, a one-dimensional plane-layer model is used to approximate the effect of contrasting velocities.

1.3.6.4.4 Soil Properties

SRS is located on soils (sedimentary strata) ranging in thickness from 600 to 1,500 ft (180 to 460 m) overlying crystalline or Triassic basement. A sitewide design basis spectrum must account for the range and variability in SRS soil properties. Deep stiff soils, such as those present at SRS, severely condition bedrock spectra by frequency-dependent amplification or deamplification. Depending upon the frequency and amplitude of bedrock motion, the key soil properties controlling the soil spectrum are the soil column thickness, the dynamic properties (strain dependent shear-modulus ratio and damping), low-strain soil shear-wave velocity structure, and impedance contrast with the basement. Section 1.3.5 indicates that the geology and soils present at the MFFF site are consistent with subsurface conditions found throughout SRS and F Area.

The *MOX Fuel Fabrication Facility Site Geotechnical Report* (DCS 2001) contains a detailed presentation of the site investigations that have been conducted and the results of site-specific analyses. Section 3.4 of DCS 2001 demonstrates the applicability of the SRS site generic PSHA to the MFFF site. Similarly, independent analyses by WSRC (WSRC 2001b) have confirmed that the sitewide "committed" criteria are "confirmed" to be applicable to the MFFF site. Sections 5 and 6 of DCS 2001 present the MFFF site subsurface conditions and engineering properties for the MFFF site, respectively. The analysis of the site-specific subsurface conditions at the MFFF site "confirms" that they are consistent with development of SRS sitewide design spectra and that these can be used as design bases for MFFF seismic design.

To accommodate the range of shear wave-velocity in the soil column, a database of velocity profiles was compiled for SRS. This database contains the range of soil and rock shear-wave velocities available from various borings and seismic surveys that have been conducted at SRS using seismic cross-hole, down-hole, velocity logger, and refraction techniques. The shallow profiles database for SRS is based primarily on site-specific seismic piezocone penetration test soundings (SCPTU). An example of SCPTU shear-wave velocity profile is shown in Figure 1.3.6-17. Other velocity profiles consist of cross-hole and down-hole seismic surveys. The deeper soil profiles are based on measurements made in five deep boreholes drilled to basement at SRS.

Other, more numerous, deep holes are used for stratigraphic purposes and to estimate the elevation of the top of bedrock. Nearly all of the velocity data are from the SRS F, H, A, K, and L Areas, and the proposed New Production Reactor site.

Basement shear-wave velocities are estimated from compressional-wave velocities measured at SRS. These velocities were collected using seismic refraction techniques. These data show that there is a significant shear-wave velocity contrast in the SRS basement between the Dunbarton

Triassic basin rock and crystalline rock. The Pen Branch fault is the demarcation for basement contrasts in velocity.

Predicted peak soil strains for SRS are sufficient to exceed the linear range of the constitutive relations (stress-strain). Consequently, laboratory testing of site-specific soil samples was required for reliable ground motion prediction of all critical facilities.

The normalized shear modulus and damping ratio versus shear strain relationships were developed for specific stratigraphic layers. Stratigraphic formation identification and their corresponding dynamic properties were developed specifically for SRS by K.H. Stokoe of the University of Texas (Stokoe et al. 1995; Lee 1996).

Stokoe et al. compiled a dynamic soil property database from available SRS reports on dynamic soil properties and new dynamic measurements made by the University of Texas. The SRS areas from which data were obtained are as follows:

1. Area of the Pen Branch Fault Confirmatory Drilling Program
2. H-Area ITP
3. H-Area RTF
4. H-Area Building 221-H
5. Proposed New Production Reactor site
6. Par Pond Dam
7. K-Reactor Area
8. Burial Ground Expansion
9. L-Reactor Area
10. L-Area Cooling Pond Dam
11. F-Area Sand Filter Structure.

These 11 areas represent eight general locations at SRS.

Figure 1.3.6-18 illustrates the University of Texas recommended normalized mean shear modulus versus cyclic strain by formation. Figure 1.3.6-19 summarizes the hysteric damping vs cyclic shear strain by formation. These curves form the basis for the dynamic properties used in the site response analysis. Figures 1.3.6-18 and 1.3.6-19 summarize cyclic shear strain and damping for SRS.

1.3.6.4.4.1 Velocity Model Parameterization

An SRS generic shear-wave velocity profile was developed from the location-specific data and includes randomness in both stratigraphic layer thickness and velocity. Because the area-specific simulations were generally consistent with the generic simulations, the SRS generic (sitewide) simulation is applied to all areas of SRS. There is no significant reduction in the site amplification variability by applying area-specific velocity model simulations for ground motion evaluations. This SRS generic shear-wave velocity profile is appropriate for use at the MFFF site.

1.3.6.5 Current SRS Design Response Spectra

This section defines the current SRS design criteria for DOE moderate hazard (PC-3) and high hazard (PC-4) facilities.

The current DOE PC-3 and PC-4 sitewide spectra are based on *Savannah River Site Seismic Response Analysis and Design Basis Guidelines* (Lee et al. 1997) developed in 1997 and incorporate variability in soil properties and soil column thickness. Following the development of PC-3 and PC-4 design basis spectra and the PC-1 and PC-2 design basis spectra, additional conservatisms were applied to the PC-3 spectral shape at high and intermediate frequencies. The shape change was incorporated in WSRC Engineering Standard 01060 (WSRC 1999a). The shape change, illustrated in Figure 1.3.6-20, increased the low-frequency (0.1 to 0.5 Hz) portion of the PC-3 spectrum and also increased intermediate frequencies (1.6 to 13 Hz) of the design basis spectrum.

The WSRC Civil/Structural Committee reviewed the DOE PC-1 and PC-2 design spectra and recommended to the Engineering Standards Board that the current Uniform Building Code be used for the Site Engineering Standard (WSRC 1999a). The basis for the decision was that the Uniform Building Code was more conservative than the WSRC (Lee 1998) spectra.

1.3.6.6 Summary of Methodology for Development of SRS Sitewide Probabilistic Seismic Hazard Assessment (PSHA)

A disciplined, systematic approach is used to develop the PC-3 and PC-4 site-wide design spectra, and includes the contributions of national and international consultants, oversight groups and panels to validate the procedures and results. The resulting baseline data are used for selection of design bases for the MFFF.

1.3.6.6.1 General

The development of the SRS PC-3 and PC-4 seismic design spectra that form the technical basis for selecting the MFFF Design Earthquake is documented in WSRC 1997c.

The multi-discipline WSRC Site Geotechnical Services (SGS) Department, formed in 1992 to provide centralized geological, seismological, geotechnical (GSG), and geo-environmental services for SRS, uses modern, comprehensive, accurate GSG data and models. WSRC performed the work in support of the MFFF in accordance with the WSRC Quality Assurance (QA) program and Criterion 1-6 and 15-18 of ASME/NQA-1-1989. DCS has approved WSRC as a supplier of services. Section 15 of the CAR provides additional details regarding quality control and review.

"Tier 1" documentation includes the reports and its appendices prepared by WSRC's SGS in response to sitewide geoscience activities, including ground motion initiatives, and in support of critical mission facilities. For example, WSRC 1997c is an example of a report prepared in support of a sitewide initiative to develop seismic design spectra using a Probabilistic PSHA approach with a deterministic historical check. Other reports related to ground motion include WSRC 1998 and WSRC 1999d. National and international experts in geology, seismology and geotechnical engineering supported the preparation of these reports.

"Tier 2" documentation consists of the much larger body of background information maintained by SGS that comprises the analysis documentation and the results of reviews by various oversight groups and panels. These documents are prepared and checked in accordance with WSRC procedures. WSRC 2001b, which demonstrates that the soil properties at the MFFF site fall within the range used to develop the SRS PC-3 and PC-4 seismic design spectra, is an example of "Tier 2" documentation. "Tier 2" documentation also includes the records of reviews by independent oversight groups and panels.

Peer reviews of past WSRC reports by industry experts have contributed through assistance and review of development of the approach used for geotechnical investigations and seismic design of structures.

In addition to reviews conducted in development of the SRS sitewide criteria, DCS also initiated a series of peer reviews of appropriate technical topics during the development of the MFFF design. The MFFF Structural Consulting Board (SCB) was formed and chartered to provide senior oversight for overall MFFF design approaches and to perform periodic reviews of in-process results. The SCB included recognized industry experts, as well as subject matter experts from within the DCS companies. SCB members have been involved in the selection of the design bases for the MFFF, and have concurred in their selection. Similarly, the MFFF Site Geotechnical Report was the subject of a detailed peer review by a panel of industry experts.

1.3.6.6.2 Comparisons with Other PSHA Studies

Section 4.0 of NUREG/CR-5250 (Bernreuter et al. 1989) compares the results of NUREG/CR-5250 with previous results from LLNL and previous studies by others. The comparisons show good agreement.

WSRC has evaluated the differences between the building code hazard assessment (National Earthquake Hazard Reduction Program - NEHRP) and the site-specific hazard evaluations used for SRS building code design (WSRC 1999d). WSRC also compared the SRS site-specific bedrock hazard with the USGS hazard, corrected to account for SRS conditions (Frankel 1999; WSRC 1999d).

The USGS hazard was prepared for use in building codes, and not for use in developing seismic hazard input for nuclear facility design. Since the DOE- and NRC-accepted hazard definitions are the EPRI and LLNL hazards, WSRC has maintained the site-wide criteria developed using those hazards, and DCS has accepted those criteria as inputs for selecting the MFFF design earthquake.

1.3.6.6.3 PSHA Methodology

A PSHA incorporates the source zone definition and ground motion prediction assessments required for a deterministic approach, but also considers the estimated rates of occurrence of earthquakes, and explicitly incorporates the uncertainties in all parameters. This approach predicts the probability of exceeding a particular ground motion value at a location during a specified period of time. This approach is useful for hazard mitigation of spatially distributed facilities having different risk factors. Details of PSHA methodology is provided in WSRC

1997c and WSRC 1998. DOE STD-1023-95 (DOE 1996b) and the SRS Site-Specific PSHA are discussed below.

1.3.6.6.3.1 DOE STD-1023-95

This standard provides guidelines for developing site-specific probabilistic seismic hazard assessments, and criteria for determining ground motion parameters for the design earthquakes. It also provides criteria for determination of design response spectra. Five performance categories are specified, from Performance Category 0 (PC-0) for SSCs that require no hazard evaluation, to design of PC-4, a desired performance level comparable to commercial nuclear power plants. These criteria address weaknesses in prior guidance by specifying Uniform Hazard Spectrum (UHS) controlling frequencies, requiring a site-specific spectral shape and a historic earthquake check, to assure that the Design Earthquake (DE) contains sufficient breadth to accommodate anticipated motions from historic earthquakes above moment magnitude (Mw) 6.

The fundamental elements of the criteria for higher hazard nuclear facilities (PC-3 and PC-4) are as follows:

1. A probabilistic seismic hazard assessment (PSHA) must be conducted for the site (or use an existing PSHA that is less than 10 years old).

2. A target DE response spectrum is defined by the mean UHS.

3. Mean UHS shapes are checked by median site-specific spectral shapes, which are derived from de-aggregated PSHA earthquake source parameters. The median site-specific spectral shapes are scaled to the UHS at two specific frequencies (average 1-2.5, and 5-10 Hz).

4. Estimated site-specific ground motions from historical earthquakes (significant felt or instrumental with Mw > 6) are developed using best estimate magnitude and distance.

5. Spectral shapes are adjusted until DE response spectra have a smooth site-specific shape.

6. Probabilistic assessment of ground failure should be applied if necessary (i.e., wherever there may be instances of liquefaction or slope failure).

Recently, NEHRP-97 criteria have been adopted by WSRC and DOE for evaluation of spectra for PC-1 and PC-2 facilities and structures. DOE-STD-1023-95 (DOE 1996b) allows the use of building codes and/or alternate design criteria for PC-1 and PC-2 design. The NEHRP design criteria is defined as 2/3 of the maximum considered earthquake ground motion (i.e., 2/3 of the 2500 year UHS). WSRC 1999d, discussed in Section 1.3.6.6.3, provides a comparison of the UHS derived from the computed site-specific hazard (referred to as USGS soil surface hazard) to the NEHRP (BSSC 1997) spectrum for the SRS. This comparison was of particular interest for deep-soil eastern U.S. sites, because it compared a building code design spectrum to a site-specific spectrum using the same hazard model and identical criteria.

1.3.6.6.3.2 SRS-Specific Probabilistic Seismic Hazard Assessments

An SRS-specific PSHA is dependent upon the local geological and geotechnical properties at the particular site or facility location. Past PSHAs, specifically those conducted by EPRI (NEI 1994) and LLNL (Bernreuter 1997; Savy 1996) for SRS, did not incorporate these detailed site properties, and consequently, those soil hazard results were not appropriate for use at the SRS. An SRS-specific PSHA should account for soil properties derived from site geological, geophysical, geotechnical, and seismic investigations (WSRC 1997c). An SRS-specific PSHA was developed using EPRI and LLNL bedrock outcrop hazard and SRS site properties including soil column thickness, soil and bedrock shear-wave velocity, and dynamic properties (WSRC 1998).

The bedrock seismic hazard evaluations used for the SRS-specific soil surface hazard were the EPRI and LLNL results for bedrock for the SRS and vicinity (a later evaluation was completed using the U.S. National Map bedrock seismic hazard (WSRC 1999d; Frankel et al. 1996). These evaluations did not revise or confirm in any way the experts' evaluations of activity rates, seismic source zonation, or the decay of ground motion with distance used in EPRI and LLNL seismic hazard assessments. The analysis results in an SRS-specific hazard evaluation for a soil site by continuing the hazard from bedrock to the soil surface using detailed soil response functions. Earthquake magnitude and ground motion level dependence of the site response is accommodated by applying site response functions consistent with the distribution of earthquake magnitude and ground motion levels obtained from disaggregating the bedrock uniform hazard spectrum.

Frequency and ground motion level dependent soil amplification functions (SAFs) developed in WSRC 1997c were used to account for the observed variations in properties throughout the SRS including: soil column thickness, stratigraphy, shear-wave velocity, and material dynamic properties, as well as basement properties. SAFs (frequency dependent ratio of soil response to bedrock input) were derived in WSRC 1997c by performing a statistical analysis of the response of bedrock spectra through realizable soil columns bounded by the observed variations in soil-column properties over the SRS. Ground motion level dependent distributions of SAFs were derived for each of six soil categories: three on crystalline basement and three on Triassic basement. Those SAF distributions were used to compute soil surface hazard.

The methodology to compute soil surface hazard was formalized by Cornell (1997). The technique is to difference the bedrock hazard disaggregation for a suite of bedrock motions and sum the probability of exceedance of surface motions using the appropriate magnitude and ground motion level-dependent soil/rock transfer functions. The approach yields soil surface hazard that would be obtained from correctly applying local site soil transfer functions to the ground motion attenuation model used in a PSHA. The analysis is repeated at the oscillator frequencies available in the bedrock hazard disaggregation and for each soil column thickness and bedrock type. The envelope of the hazard curves is taken from the soil and bedrock categories.

As discussed in Sections 1.3.5 and 1.3.6.4.4, the analysis of the site-specific subsurface conditions at the MFFF site indicates that the geology and soils present at the MFFF site are consistent with subsurface conditions found throughout SRS and F Area. Therefore, the SRS sitewide hazard can be used for the MFFF seismic design.

1.3.6.6.4 Results

The PC-3 and PC-4 site-wide design spectra implement DOE-STD-1023-95 (DOE 1996b), which specifies a broadened mean-based UHS representing a specified annual probability of exceedance (for a SSC performance category) and a historical earthquake deterministic spectrum that ensures breadth of the UHS. For SRS, the deterministic spectrum is represented by a repeat of the 1886 Charleston earthquake. The development of the SRS design basis spectra uses a statistical methodology to verify that a mean-based response is achieved at the soil free surface.

The EPRI and LLNL bedrock level uniform hazard spectra were averaged and broadened per DOE-STD-1023-95. Available SRS soil data were used to parameterize the soil shear-wave velocity profile. The parameterization was used to establish statistics on site response for ranges of soil column thickness present at SRS. The mean soil UHS was obtained by scaling the bedrock UHS by the ground motion dependent mean site amplification functions.

The soil data used to develop the sitewide spectra incorporate the available SRS velocity and dynamic property database available to about mid-1996. The spectra are based on soil properties and stratigraphy from specific locations at the SRS, and are parameterized to represent the variability in measured properties. Because of the potential for variation of soil properties in excess of what have been measured at the SRS, the design basis spectra are issued as a sitewide commitment for DOE facilities in accordance with the WSRC quality assurance program. Each project is required to confirm the applicability of the sitewide spectra to its project site. The soil parameters available at the specific site or facility where it is being used must be reviewed and determined to be consistent with the data parameterized in the study. The results of this review for the MFFF site are provided in the Tier 2 document WSRC 2001b. As discussed in Sections 1.3.5 and 1.3.6.4.4 of the CAR, the analysis of the site-specific subsurface conditions at the MFFF site indicates that the geology and soils present at the MFFF site are consistent with subsurface conditions found throughout SRS and F Area. Therefore, the SRS sitewide hazard can be used for the MFFF seismic design.

The current PC-3 and PC-4 sitewide spectra are based on the WSRC analysis developed in 1997 and incorporate variability in soil properties and soil column thickness. The design basis spectra for PC-3 and PC-4 are given in Figure 1.3.6-13 and Figure 1.3.6-14, respectively. After the development of PC-3 and PC-4 design basis spectra and the PC-1 and PC-2 design basis spectra, additional conservatisms were applied to the PC-3 spectral shape at high and intermediate frequencies, and the shape change was incorporated in the Site Engineering Standard (WSRC 1999a). The shape change, illustrated in Figure 1.3.6-20, increased the low-frequency (0.1-0.5 Hz) portion of the PC-3 spectrum and also increased intermediate frequencies (1.6-13 Hz) of the design basis spectrum.

1.3.6.7 Definition of the MFFF Design Earthquake

Previous sections have presented the basis for establishing seismic criteria for DOE PC-3 and PC-4 SSCs at SRS. Soil surface hazard relationships (acceleration versus mean annual probability of exceedance) presented in WSRC 1998 are used to evaluate the relative probability of exceedance of the PC-3 and PC-4 accelerations and the accelerations of intermediate spectra. Figure 1.3.6-20 shows the current PC-3 ground surface spectrum at 5% damping, while Figure 1.3.6-14 shows the current PC-4 ground surface spectrum. The MFFF-specific geotechnical data are consistent with the SRS-specific data used to develop the PC-3 and PC-4 design spectra. The application of the PC-3 and PC-4 design spectra is confirmed to be appropriate for the MFFF site in accordance with WSRC 1997c. Therefore, based on the site-specific MFFF geotechnical data (DCS 2001), the SRS PC-3 and PC-4 design spectra are also MFFF site-specific. The PC-3 and PC-4 design spectra are conservative spectra with probabilities of exceedance of 5×10^{-4}/yr and 1×10^{-4}/yr, respectively, based on evaluation of SRS-specific soil surface hazard curves (WSRC 1997c; WSRC 1998). Because the PC-3 design spectrum is also MFFF site-specific, it has a consistent probability of exceedance (5×10^{-4}/yr) at each oscillator frequency and envelopes the 5×10^{-4}/yr uniform hazard spectrum.

Using the acceleration hazard relationships shown in Figure 1.3.6-24 for each of the four oscillator frequencies (1 Hz, 2.5 Hz, 5 Hz, and 10 Hz) represented in the hazard chart, the spectral acceleration can be read off each of the 5% damped response spectra (Figure 1.3.6-20 for PC-3, Figure 1.3.6-14 for PC-4, and Figure 1.3.6-21 for Regulatory Guide 1.60). These spectral accelerations are used to enter Figure 1.3.6-24 and to read the associated annual mean probability of exceedance. Inverting the annual mean probability of exceedance results in the return period shown in Table 1.3.6-7. These surface accelerations represent approximately 2,700-year and 22,000-year surface accelerations at 5 Hz for the PC-3 and PC-4 spectra, respectively.

To achieve safety performance goals (i.e., to ensure that high consequence events are highly unlikely), conservative design criteria between these two spectra are selected for the MFFF. Figure 1.3.6-21 compares a Regulatory Guide 1.60 5% spectrum scaled to a PGA of 0.20g to the surface spectra for PC-3 and PC-4 facilities. It can be seen that the Regulatory Guide 1.60 spectrum significantly envelops the PC-3 spectrum in frequency ranges of significant structural interest. The return period of representative acceleration ordinates can be determined in the same way as it was for PC-3 and PC-4 above (Table 1.3.6-7).

The 0.2g Regulatory Guide 1.60 spectrum envelopes the PC-3 spectrum, and therefore, has even lower probabilities of exceedance than the PC-3 spectrum. Figure 1.3.6-23 compares the 0.2g Regulatory Guide 1.60 spectrum to the soil surface uniform hazard spectrum at four frequencies (1, 2.5, 5 and 10 Hz). It can be seen that at a frequency of 1 Hz, the spectral acceleration for the MFFF design spectrum is less than the 10,000-year UHS. For frequencies of practical structural interest, 2.5, 5 and 10 Hz, the spectral acceleration ordinates for the 0.2g Regulatory Guide 1.60 soil surface design earthquake are greater than the 10,000-year UHS. Appendix C of DOE 1994 presents an evaluation that shows that a median annual probability of exceedance of 10^{-5} corresponds approximately to a mean annual probability of exceedance of 10^{-4}. By selecting accelerations consistent with a (10,000-year) 10^{-4}/yr mean annual probability of exceedance, this spectrum meets the intent of Regulatory Guide 1.165, which suggests a 10^{-5}/yr median annual probability of exceedance.

On this basis, a 0.2g Regulatory Guide 1.60 horizontal spectrum is selected as the soil surface design earthquake spectrum for design of MFFF buildings and structures. For evaluation of subsurface conditions, to include liquefaction and dynamic settlements, bedrock motions based on the SRS PC-3 bedrock spectrum will be used, scaled so that when amplified through the site soil profile, the resulting surface ground motion will have 0.20g PGA.

Initial evaluations of SRS earthquake hazards for the MFFF did not indicate that near-field (closer than 9.3 mi [15 km]) earthquakes would be dominant.

WSRC-TR-99-00271, *Computation of USGS Soil UHS and Comparison to NEHRP and PC-1 Response Spectra for the SRS* (WSRC 1999d), indicated that although the near-field earthquakes are not dominant, their contribution is potentially significant. WSRC-TR-2001-00342, *Development of MFFF-Specific Vertical-to-Horizontal Seismic Spectral Ratios* (WSRC 2001a) indicated that the vertical component would be greater than the initially selected 2/3 ratio.

ASCE 4-98 recommends that if near-field earthquakes are dominant, the ratio of vertical to horizontal spectral ordinates be taken as, at least, unity for frequencies above 5 Hz, 2/3 for frequencies below 3 Hz, and a transition between 3 Hz and 5 Hz. This is closely and conservatively approximated by the Regulatory Guide 1.60 vertical spectrum scaled to the same 0.2g PGA. Therefore, for the MFFF, the vertical component of earthquake motion at the soil surface will be selected as the Regulatory Guide 1.60 vertical spectrum scaled to 0.2g PGA. This results in vertical and horizontal spectra that are consistent with the guidance in ASCE 4-98 and Regulatory Guide 1.60, and appropriately consider the effects of near-field earthquakes. Figure 1.3.6-22 illustrates the selected design earthquake response spectrum.

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Tables

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Table 1.3.6-1. Significant Earthquakes Within 200 Miles of the SRS with Modified Mercali Intensities ≥ IV and/or Magnitudes ≥ 3

DATE yr/mm/dd	Latitude Deg. N	Longitude Deg. W	Depth km	Magnitude(s) *	MMI	Distance Mile †
1776/11/05	35.2	83.0			IV	155
1799/04/04	32.9	80.0			V	98
1799/04/11	32.9	80.0			V	98
1799/04/11	32.9	80.0			V	98
1817/01/08	32.9	80.0			V	98
1820/09/03	33.4	79.3			IV	135
1827/05/11	36.1	81.2			IV	198
1851/08/11	35.6	82.6			V	171
1853/05/20	34.0	81.2			VI	57
1857/12/19	32.9	80.0			V	98
1860/01/19	32.9	80.0			V	98
1861/08/31	36.1	81.1			VI	198
1869	32.9	80.0			IV	98
1872/06/17	33.1	83.3			V	97
1874/02/10	35.7	82.1			V	171
1874/02/22	35.7	82.1			IV	171
1874/03/17	35.7	82.1			IV	171
1874/03/26	35.7	82.1			IV	171
1874/04/14	35.7	82.1			IV	171
1874/04/17	35.7	82.1			IV	171
1875/11/02	33.8	82.5			VI	63
1876/12/12	32.9	80.0			IV	98
1879/12/13	35.2	80.8			IV	142
1885/08/06	36.2	81.6			V	203
1885/10/17	33.0	83.0			IV	81
1886/08/27	32.9	80.0			V	98
1886/08/28	32.9	80.0			VI	98
1886/08/28	32.9	80.0			IV	98
1886/08/28	32.9	80.0			IV	98
1886/09/01	30.4	81.7			IV	197
1886/09/01	32.9	80.0		6.9F	X	98
1886/09/01	32.9	80.0			V	98
1886/09/02	32.9	80.0			V	98
1886/09/03	30.4	81.7			IV	197
1886/09/04	32.9	80.0			V	98
1886/09/04	30.4	81.7			IV	197
1886/09/05	30.4	81.7			IV	197
1886/09/06	32.9	80.0			V	98
1886/09/06	32.9	80.0			IV	98
1886/09/08	30.4	81.7			IV	197
1886/09/09	30.4	81.7			IV	197
1886/09/17	32.9	80.0			VI	98
1886/09/21	32.9	80.0			VI	98
1886/09/21	32.9	80.0			V	98

Table 1.3.6-1. Significant Earthquakes Within 200 Miles of the SRS with Modified Mercali Intensities ≥ IV and/or Magnitudes ≥ 3 (continued)

DATE yr/mm/dd	Latitude Deg. N	Longitude Deg. W	Depth km	Magnitude(s) *	MMI	Distance Mile †
1886/09/27	32.9	80.0			VI	98
1886/09/27	32.9	80.0			V	98
1886/10/09	32.9	80.0			IV	98
1886/10/09	32.9	80.0			IV	98
1886/10/09	32.9	80.0			V	98
1886/10/22	32.9	80.0			VI	98
1886/10/22	32.9	80.0			VII	98
1886/10/23	32.9	80.0			IV	98
1886/11/05	32.9	80.0			VI	98
1886/11/28	32.9	80.0			IV	98
1887/01/04	32.9	80.0			V	98
1887/03/04	32.9	80.0			IV	98
1887/03/17	32.9	80.0			V	98
1887/03/18	32.9	80.0			IV	98
1887/03/19	32.9	80.0			IV	98
1887/03/24	32.9	80.0			IV	98
1887/03/24	32.9	80.0			IV	98
1887/03/28	32.9	80.0			IV	98
1887/04/07	32.9	80.0			IV	98
1887/04/08	32.9	80.0			IV	98
1887/04/10	32.9	80.0			IV	98
1887/04/14	32.9	80.0			IV	98
1887/04/26	32.9	80.0			IV	98
1887/04/28	32.9	80.0			V	98
1887/05/06	32.9	80.0			IV	98
1887/06/03	32.9	80.0			IV	98
1887/07/10	32.9	80.0			IV	98
1887/08/27	32.9	80.0			V	98
1887/08/27	32.9	80.0			IV	98
1888/01/12	32.9	80.0			VI	98
1888/01/16	32.9	80.0			IV	98
1888/02/29	32.9	80.0			V	98
1888/03/03	32.9	80.0			IV	98
1888/03/03	32.9	80.0			IV	98
1888/03/04	32.9	80.0			IV	98
1888/03/14	32.9	80.0			V	98
1888/03/20	32.9	80.0			IV	98
1888/03/25	32.9	80.0			IV	98
1888/04/16	32.9	80.0			IV	98
1888/04/16	32.9	80.0			IV	98
1888/05/02	32.9	80.0			IV	98
1889/02/10	32.9	80.0			IV	98
1889/07/12	32.9	80.0			IV	98
1891/10/13	32.9	80.0			IV	98
1893/06/21	32.9	80.0			V	98

Table 1.3.6-1. Significant Earthquakes Within 200 Miles of the SRS with Modified Mercali Intensities ≥ IV and/or Magnitudes ≥ 3 (continued)

DATE yr/mm/dd	Latitude Deg. N	Longitude Deg. W	Depth km	Magnitude(s) *	MMI	Distance Mile †
1893/06/21	30.4	81.7			IV	197
1893/07/05	32.9	80.0			IV	98
1893/07/06	32.9	80.0			IV	98
1893/07/08	32.9	80.0			IV	98
1893/07/08	32.9	80.0			IV	98
1893/09/19	32.9	80.0			IV	98
1893/09/19	32.9	80.0			IV	98
1893/09/19	32.9	80.0			IV	98
1893/11/08	32.9	80.0			IV	98
1893/11/08	32.9	80.0			IV	98
1893/12/27	32.9	80.0			IV	98
1893/12/27	32.9	80.0			IV	98
1893/12/27	32.9	80.0			IV	98
1893/12/27	32.9	80.0			IV	98
1893/12/28	32.9	80.0			IV	98
1894/01/10	32.9	80.0			IV	98
1894/01/10	32.9	80.0			IV	98
1894/01/10	32.9	80.0			IV	98
1894/01/30	32.9	80.0			IV	98
1894/02/01	32.9	80.0			IV	98
1894/06/16	32.9	80.0			IV	98
1894/12/11	32.9	80.0			IV	98
1895/01/08	32.9	80.0			IV	98
1895/01/08	32.9	80.0			IV	98
1895/01/08	32.9	80.0			IV	98
1895/04/27	32.9	80.0			IV	98
1895/07/25	32.9	80.0			IV	98
1895/10/06	32.9	80.0			IV	98
1895/10/20	32.9	80.0			IV	98
1895/11/12	32.9	80.0			IV	98
1896/03/19	32.9	80.0			IV	98
1896/08/11	32.9	80.0			IV	98
1896/08/11	32.9	80.0			IV	98
1896/08/11	32.9	80.0			IV	98
1896/08/11	32.9	80.0			IV	98
1896/08/12	32.9	80.0			IV	98
1896/08/14	32.9	80.0			IV	98
1896/08/30	32.9	80.0			IV	98
1896/09/08	32.9	80.0			IV	98
1896/11/14	32.9	80.0			IV	98
1899/03/10	32.9	80.0			IV	98
1899/12/04	32.9	80.0			IV	98
1900/10/31	30.4	81.7			V	197
1901/12/02	32.9	80.0			IV	98
1903/01/24	32.9	80.0			IV	98
1903/01/24	32.1	81.1			VI	85

Table 1.3.6-1. Significant Earthquakes Within 200 Miles of the SRS with Modified Mercali Intensities ≥ IV and/or Magnitudes ≥ 3 (continued)

DATE yr/mm/dd	Latitude Deg. N	Longitude Deg. W	Depth km	Magnitude(s) *	MMI	Distance Mile †
1903/01/31	32.9	80.0			IV	98
1903/02/03	32.9	80.0			IV	98
1904/03/05	35.7	83.5		4.0F	V	200
1907/04/19	32.9	80.0			V	98
1911/04/20	35.1	82.7			V	141
1912/06/12	32.9	80.0			VII	98
1912/06/20	32.0	81.0			V	94
1912/09/29	32.9	80.0			IV	98
1912/10/23	32.7	83.5			IV	115
1912/11/17	32.9	80.0			IV	98
1912/12/07	34.7	81.7			IV	100
1913/01/01	34.7	81.7			VII	100
1913/04/17	35.3	84.2		3.9F	V	204
1914/03/05	33.5	83.5			VI	110
1914/03/07	34.2	79.8			IV	124
1914/07/14	32.9	80.0			IV	98
1914/09/22	32.9	80.0			V	98
1915/10/29	35.8	82.7			IV	186
1915/10/29	35.8	82.7			V	186
1916/02/21	35.5	82.5			VII	163
1916/03/02	34.5	82.7			IV	106
1916/08/26	36.0	81.0			V	193
1924/01/01	34.8	82.5			IV	118
1924/10/20	35.0	82.6			V	133
1926/07/08	35.9	82.1			VII	184
1928/11/03	36.112	82.828	5.0	4.5N	VI	208
1928/11/20	35.8	82.3			IV	180
1928/12/23	35.3	80.3			IV	160
1929/01/03	33.9	80.3			IV	89
1929/10/28	34.3	82.4			IV	85
1930/12/10	34.3	82.4			IV	85
1930/12/26	34.5	80.3			IV	115
1931/05/06	34.3	82.4			IV	85
1933/12/19	32.9	80.0			IV	98
1933/12/23	32.9	80.0			V	98
1933/12/23	32.9	80.0			IV	98
1934/12/09	32.9	80.0			IV	98
1935/01/01	35.1	83.6			V	170
1938/03/31	35.6	83.6			IV	197
1940/12/25	35.9	82.9			IV	196
1941/05/10	35.6	82.6			IV	171
1943/12/28	32.9	80.0			IV	98
1944/01/28	32.9	80.0			IV	98
1945/01/30	32.9	80.0			IV	98
1945/07/26	33.750	81.376	5.0	4.4F	VI	37
1947/11/02	32.9	80.0			IV	98

Table 1.3.6-1. Significant Earthquakes Within 200 Miles of the SRS with Modified Mercali Intensities ≥ IV and/or Magnitudes ≥ 3 (continued)

DATE yr/mm/dd	Latitude Deg. N	Longitude Deg. W	Depth km	Magnitude(s) *		MMI	Distance Mile †
1949/02/02	32.9	80.0				IV	98
1949/06/27	32.9	80.0				IV	98
1951/03/04	32.9	80.0				IV	98
1951/12/30	32.9	80.0				IV	98
1952/11/19	32.9	80.0				V	98
1956/01/05	34.3	82.4				IV	85
1956/01/05	34.3	82.4				IV	85
1956/05/19	34.3	82.4				IV	85
1956/05/27	34.3	82.4				IV	85
1956/09/07	35.5	84.0			4.1F	V	206
1957/05/13	35.799	82.142	5.0		4.1F	VI	178
1957/07/02	35.6	82.7	7.0			VI	173
1957/11/24	35.	83.5			4.0F	VI	161
1958/05/16	35.6	82.6				IV	171
1958/10/20	34.5	82.7				V	106
1959/08/03	33.054	80.126	1.0		4.4F	VI	88
1959/10/27	34.5	80.2				VI	119
1960/01/03	35.9	82.1				IV	184
1960/03/12	33.072	80.121	9.0		4.0F	V	88
1960/07/24	32.9	80.0				V	98
1963/04/11	34.9	82.4				IV	122
1963/05/04	32.972	80.193	5.0		3.3M	IV	86
1963/10/08	33.9	82.5			3.2M		67
1964/01/20	35.9	82.3				IV	186
1964/03/07	33.724	82.391	5.0		3.3M		54
1964/03/13	33.193	83.309	1.0	4.4P	3.9M	V	97
1964/04/20	33.842	81.096	3.0		3.5M	V	51
1965/09/09	34.7	81.2			3.9M		103
1965/09/10	34.7	81.2			3.0M		103
1965/11/08	33.2	83.2			3.3M		91
1967/10/23	32.802	80.221	19.0	3.8P	3.4N	V	88
1968/07/12	32.8	79.7				IV	116
1968/09/22	34.111	81.484	1.0	3.7P	3.5M	IV	60
1969/05/09	33.95	82.58			3.3N		73
1969/05/18	33.95	82.58		3.5N			73
1969/12/13	35.036	82.846	6.0		3.7M	IV	142
1970/09/10	36.020	81.421	1.0		3.1N	V	191
1971/05/19	33.359	80.655	1.0	3.4P	3.7N	V	57
1971/07/13	34.76	82.98		3.8N		VI	130
1971/07/13	34.7	82.9		3.0M			124
1971/07/31	33.341	80.631	4.0	3.8N		III	58
1971/08/11	33.4	80.7		3.5N			55
1971/10/09	35.795	83.371	8.0	3.4P	3.7N	V	202
1971/10/22	36.0	83.0		3.3M			205
1972/02/03	33.306	80.582	2.0	4.5P	4.5N	V	61
1972/02/07	33.46	80.58		3.2M		III	62

Table 1.3.6-1. Significant Earthquakes Within 200 Miles of the SRS with Modified Mercali Intensities ≥ IV and/or Magnitudes ≥ 3 (continued)

DATE yr/mm/dd	Latitude Deg. N	Longitude Deg. W	Depth km	Magnitude(s) *		MMI	Distance Mile †
1972/02/07	33.46	80.58		3.2M		III	62
1972/08/14	33.2	81.4			3.0L	III	14
1973/12/19	32.974	80.274	6.0		3.0M	III	81
1974/08/02	33.908	82.534	4.0	4.3P	4.1N	V	69
1974/10/08	33.9	82.4		3.1P		III	63
1974/10/28	33.79	81.92			3.0L	IV	41
1974/11/05	33.73	82.22			3.7L	II	47
1974/11/22	32.926	80.159	6.0	4.7P	4.3N	VI	88
1974/12/03	33.95	82.50			3.6L	IV	69
1975/04/01	33.2	83.2			3.9M		91
1975/04/28	33.00	80.22	10.0		3.0N	IV	84
1975/10/18	34.9	83.0				IV	138
1975/11/25	34.943	82.896	10.0		3.2N	IV	137
1976/12/27	32.060	82.504	14.0		3.7N	V	97
1977/01/18	33.058	80.173	1.0		3.0N	VI	86
1977/03/30	32.95	80.18	8.0		2.9D	V	87
1977/08/04	33.369	80.699	9.0		3.1N		54
1977/08/25	33.369	80.698	3.4	3.1N	2.8D	IV	54
1977/12/15	32.944	80.167	7.5	3.0N	2.6D	V	87
1978/09/07	33.063	80.210	10.0	2.7N	2.6D	IV	83
1979/08/13	35.200	84.353	22.2	3.7N	3.7D	V	206
1979/08/13	33.90	82.54	23.0		4.1D		69
1979/08/26	34.93	82.97	2.0		3.7D		139
1979/09/06	35.298	83.241	10.0		3.2D		168
1979/09/12	35.579	83.941	27.1	3.2N	3.1D	V	208
1979/12/07	33.008	80.163	5.0	2.8N	2.8D	IV	87
1980/06/10	35.458	82.815	0.6	3.0N	2.5D		167
1980/09/01	32.978	80.186	7.0	2.7N	2.9D	IV	86
1981/03/04	35.810	79.737	1.0	2.8N	2.2D	IV	206
1981/04/09	35.514	82.051	0.2	3.0N	3.3D	V	157
1981/05/05	35.327	82.422	10.2	3.5N	3.1D	V	150
1982/01/28	32.982	81.393	7.0	3.4N	2.4D		23
1982/03/01	32.936	80.138	6.7	3.0N	2.8D	IV	89
1982/07/16	34.32	81.55	2.0		3.1D	III	74
1982/10/31	32.671	84.873		2.9N	3.0D	V	193
1982/10/31	32.644	84.894		3.1N	3.1D		194
1982/12/11	32.853	83.532			3.0D		114
1983/01/26	32.853	83.558		3.5N	3.5D		115
1983/03/25	35.333	82.460	11.5	3.2N	3.3D	V	151
1983/11/06	32.937	80.159	9.6		3.3D	V	88
1985/12/22	35.701	83.720	13.4		3.3D		207
1986/02/13	34.76	82.94	5.0	3.5N		V	128
1986/03/13	33.229	83.226	5.0		2.4D	IV	93
1986/09/17	32.931	80.159	6.7		2.6D	IV	88
1987/03/16	34.560	80.948	3.0		3.1D		98
1988/01/09	35.279	84.199	12.2		3.2D	IV	203

Table 1.3.6-1. Significant Earthquakes Within 200 Miles of the SRS with Modified Mercali Intensities ≥ IV and/or Magnitudes ≥ 3 (continued)

DATE yr/mm/dd	Latitude Deg. N	Longitude Deg. W	Depth km	Magnitude(s) *		MMI	Distance Mile †
1988/01/23	32.935	80.157	7.4		3.3D	V	88
1988/02/18	35.346	83.837	2.4	3.5N	3.3D	IV	192
1989/06/02	32.934	80.166	5.8		2.0D	IV	87
1990/11/13	32.947	80.136	3.4	3.5N	3.2D	V	89
1991/06/02	32.980	80.214	5.0		1.7D	V	84
1992/01/03	33.981	82.421	3.3		3.4D	V	68
1992/08/21	32.985	80.163	6.5	4.1N	4.1D	VI	87
1993/01/01	35.878	82.086	2.3		3.0D		183
1993/08/08	33.597	81.591	8.5	3.2N	2.9D	V	24
1995/04/17	32.997	80.171	8.4	3.9N			86
1998/04/13	34.471	80.603	6.6	3.9N			103
1998/06/05	35.554	80.785	9.4	3.2N			165
1999/03/29	33.064	80.140	10.7		3.0D		87
2000/01/18	32.993	83.214	19.2	3.5N		V	93

Notes:

Table compiled for earthquakes through December 31, 2000. The primary source of data is the Southeastern U.S. Earthquake Catalog maintained by the Virginia Polytechnic Institute Seismological Observatory (VTSO). Secondary sources include the Southeastern Unites States Seismic Network Bulletin, the U.S. Geological Survey Earthquake Database, and the Advanced National Seismic System earthquake catalog. The December 12, 1987, magnitude 3.0 event appearing in the USGS database is not shown above since it is not contained in the VTSO master catalog or bulletins.

† Distances reported in the table are calculated from the center of the SRS. In some instances the distance is slightly more than 200 miles due to the point selected as the center of the SRS.

* In many instances location, depth and magnitude are determined and reported by more than one organization, which results in some minor discrepancies between catalogs. In general, when discrepancies exist, the VTSO data is reported. Generally when body-wave magnitude (m_b) is available it is reported. Magnitudes based on intensity are not reported, but the intensity is reported. In some instances more than one magnitude is reported. The magnitude type code follows the magnitude. The type codes are:

- D - Duration magnitude (M_d) from duration or coda length
- F - Body-wave magnitude (m_b) from felt area or attenuation data
- L - Richter or local magnitude (M_L)
- M - Body-wave magnitude (m_b) determined from modified instruments/formulae
- N - Body-wave magnitude (m_b) from Lg wave data
- P - Body-wave magnitude (m_b) from P wave data

Data from WSRC 2002b

Table 1.3.6-2. Modified Mercalli Intensity Scale of 1931

Level	Definition
I.	Not felt except by a very few under especially favorable circumstances (I Rossi-Forel Scale).
II.	Felt by only a few persons at rest, especially on upper floors of buildings. Delicately suspended objects may swing (I and II, Rossi-Forel Scale).
III.	Felt quite noticeably indoors, especially on upper floors of buildings, but many people do not recognize it as an earthquake. Standing motor cars may rock slightly. Vibration like passing truck. Duration estimated (III Rossi-Forel Scale).
IV.	During the day felt indoors by many; outdoors by few. At night some awakened. Dishes, windows, doors disturbed; walls made creaking sound. Sensation like heavy truck striking building. Standing motor cars rocked noticeably (IV to V Rossi-Forel Scale).
V.	Felt by nearly everyone; many awakened. Some dishes, windows, etc., broken, a few instances of cracked plaster, unstable objects overturned. Disturbance of trees, poles, and other tall objects sometimes noticed. Pendulum clocks may stop (V to VI Rossi-Forel Scale).
VI.	Felt by all; many are frightened and run outdoors. Some heavy furniture moved; a few instances of fallen plaster or damaged chimneys. Damage slight (VI to VII Rossi-Forel Scale).
VII.	Everybody runs outdoors. Damage negligible in buildings of good structures; considerable in poorly built or badly designed structures; some chimneys are broken. Noticed by persons driving motor cars (VIII Rossi-Forel Scale).
VIII.	Damage slight in specially designed structures; considerable in ordinary substantial buildings with partial collapse; great in poorly built structures. Panel walls thrown out of frame structures. Fall of chimneys, factory stacks, columns, monuments, and walls. Heavy furniture overturned. Sand and mud ejected in small amounts. Changes in well water. Disturbs persons driving motor cars (VIII+ to IX Rossi-Forel Scale).
IX.	Damage considerable in specially designed structures; well-designed frame structures thrown out of plumb; great in substantial buildings with partial collapse. Buildings shifted off foundations. Ground cracked conspicuously. Underground pipes broken (IX+ Rossi-Forel Scale).
X.	Some well-built wooden structures destroyed; most masonry and frame structures destroyed with foundations, ground badly cracked. Rails bent. Landslides considerable from riverbanks and steep slopes. Shifted sand and mud. Water splashed (slopped) over banks (X Rossi-Forel Scale).
XI.	Few, if any, masonry structures remain standing. Bridges destroyed. Broad fissures in ground. Underground pipe lines completely out of service. Earth slumps and land slips in soft ground. Rails bent greatly.
XII.	Damage total. Waves seen on ground surfaces. Lines of sight and level distorted. Objects thrown upward into the air.

Note: Data from WSRC 2000b

Table 1.3.6-3. Historic Earthquakes Recorded Within 50 Miles (80 km) of the SRS

Event #	Date	Latitude Deg. N	Longitude Deg. W	Depth (km)	Magnitude
1	05/06/1897	33.3	81.2		Felt
2	05/09/1897	33.9	81.6		Felt
3	05/24/1897	33.3	81.2		Felt
4	05/27/1897	33.3	81.2		Felt
5	8/14/1972	33.2	81.4		3.2
6	10/28/1974	33.79	81.92		3.0
7	11/5/1974	33.73	82.22		3.7
8	9/15/1976	33.144	81.413	4.5	2.4
9	6/5/977	33.052	81.412	3.5	2.7
10	2/21/1981	33.593	81.148	6.6	2.0
11	1/28/1982	32.980	81.390	7.0	3.4
12	6/9/1985	33.223	81.684	5.8	2.6
13	2/17/1988	33.511	81.697	11.7	2.5
14	8/5/1988	33.187	81.629	2.3	2.0
15	7/13/1992	33.480	81.192	7.6	1.9
16	10/2/1992	33.499	81.202	3.0	2.4
17	12/12/1992	33.280	81.833	11.8	1.2
18	6/29/1993	33.465	81.221	4.9	2.2
19	8/8/1993	33.589	81.585	10.2	3.2
20	8/8/1993	33.589	81.581	9.2	1.6
21	9/18/1996	33.692	82.125	2.4	2.8
22	5/17/1997	33.212	81.677	5.4	2.5
23	10/08/2001	33.324	81.667	3.9	2.6
24	10/08/2001	33.319	81.673	4.2	1.0
25	10/08/2001	33.332	81.676	4.2	1.4
26	10/14/2001	33.347	81.663	3.1	0.7
27	10/15/2001	33.332	81.683	5.0	0.8
28	12/17/2001	33.328	81.675	4.1	1.1
29	12/27/2001	33.331	81.665	3.8	0.1
30	03/06/2002	33.331	81.679	4.6	1.4

Notes:

- Table compiled for earthquakes through October 1, 2002.
- Locations, depths, and magnitudes for events within 50 miles of the SRS were reevaluated by SRS personnel in 2002. Magnitudes, depths, and locations reported in this table will vary slightly from magnitudes, depths, and locations reported by other sources, including Table 1.3.6-1. The updated magnitudes and locations for events within 50 miles of the SRS will be provided to Virginia Polytechnic Institute Seismological Observatory for inclusion in their database.

Data from WSRC 2002b

Table 1.3.6-4. Blume Estimated Site Motions for Postulated Maximum Events

Location	Epicentral Intensity (MMI)	R (km)	Site Intensity (MMI)	Site PGA (%g)
Local	VII	0-10	VII	0.10
Fall Line	VIII	45	VI	0.06
Bowman	X	95	VII	0.10
Middleton	X	145	VI-VII	0.075

Note: Data from WSRC 2000b

Table 1.3.6-5. Geomatrix Estimated Site Motions for Postulated Maximum Events

Location	Magnitude (Mw)	R (km)	Site PGA[a] (%g median, horizontal)
Local	5.0	<25	0.18
Bowman	6.0	80	0.06
Charleston	7.5	110	0.11

[a] 25 Hz
Note: Data from WSRC 2000b

Table 1.3.6-6. Modified Herrmann Crustal Model

H (km)	Vs (km/s)	density (g/cc)
5.0	3.75	2.7
9.5	3.76	2.7
14	4.01	2.8
infinity	4.56	3.3

Note: Data from WSRC 2000b

Table 1.3.6-7. Return Periods for Spectrum Ordinates

PC-3 Spectrum (0.16g)

Frequency (Hz)	Sa (g)	Return (yr)
1.00	0.250	4,000
2.50	0.375	3,300
5.00	0.375	2,700
10.00	0.360	5,600

PC-4 Spectrum (0.23g)

Frequency (Hz)	Sa (g)	Return (yr)
1.00	0.610	37,000
2.51	0.730	23,000
5.01	0.680	22,000
10.00	0.540	36,000

0.2g Regulatory Guide 1.60 Spectrum

Frequency (Hz)	Sa (g)	Return (yr)
1.00	0.300	6,300
2.51	0.620	14,000
5.01	0.570	10,000
10.00	0.480	22,000

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Figures

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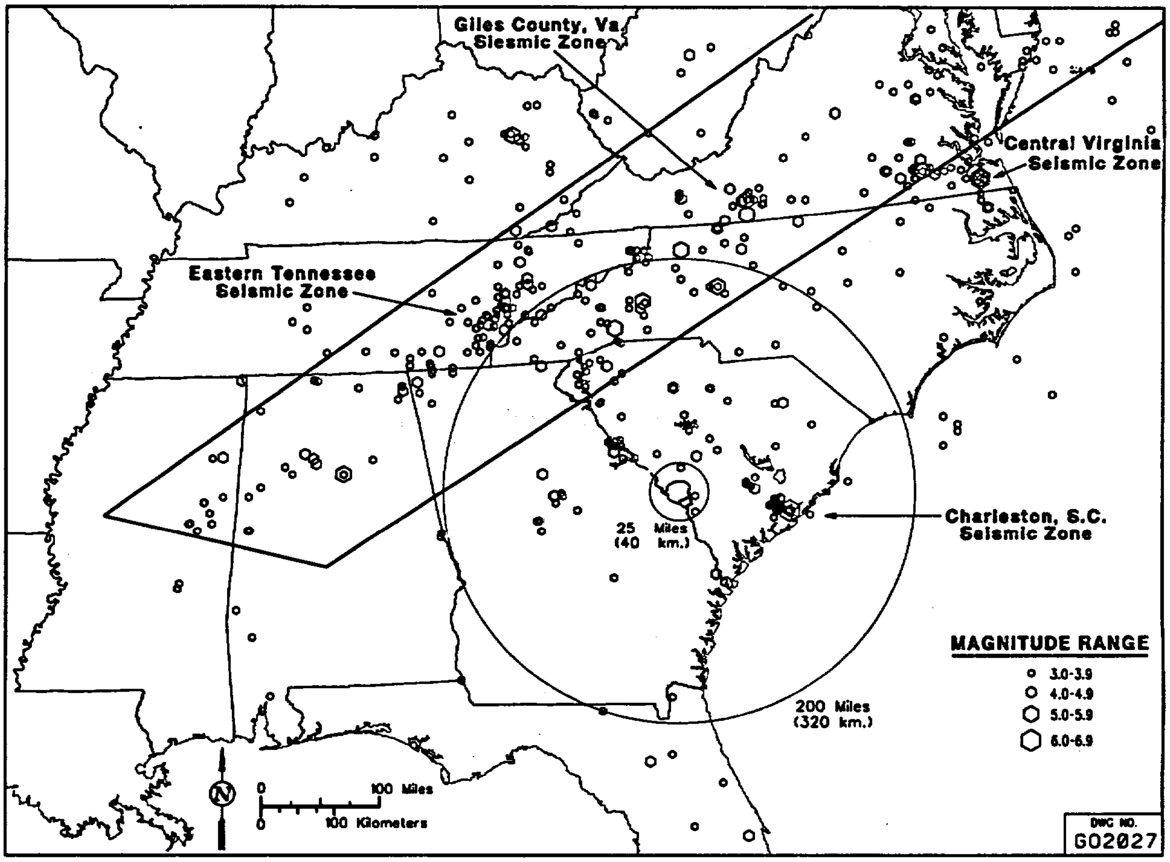

Data from WSRC 2000b

Figure 1.3.6-1. Location of Historical Seismic Events, 1568 – 1993

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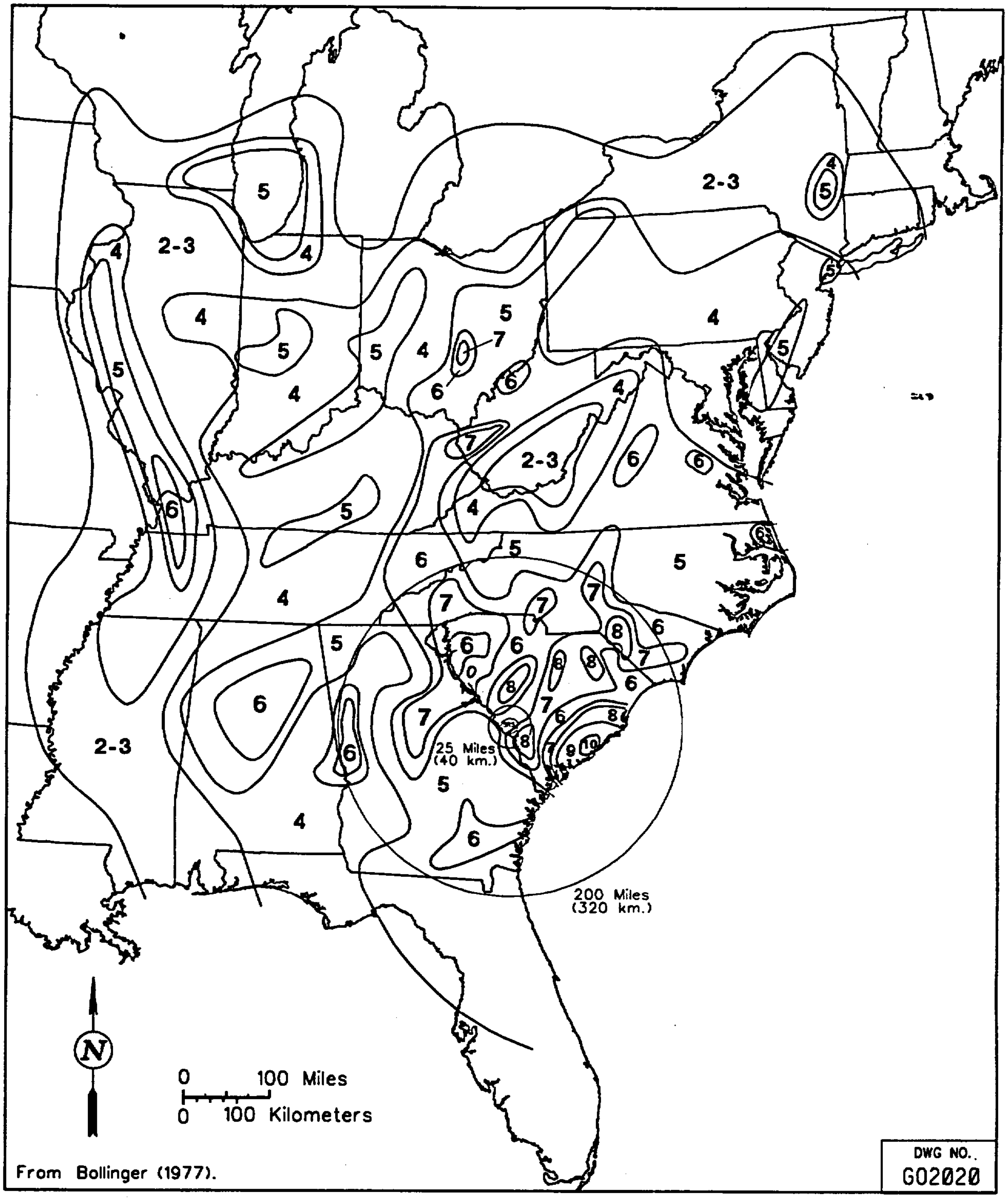

Data from WSRC 2000b

Figure 1.3.6-2. MMI Intensity Isoseismals for the Charleston Event

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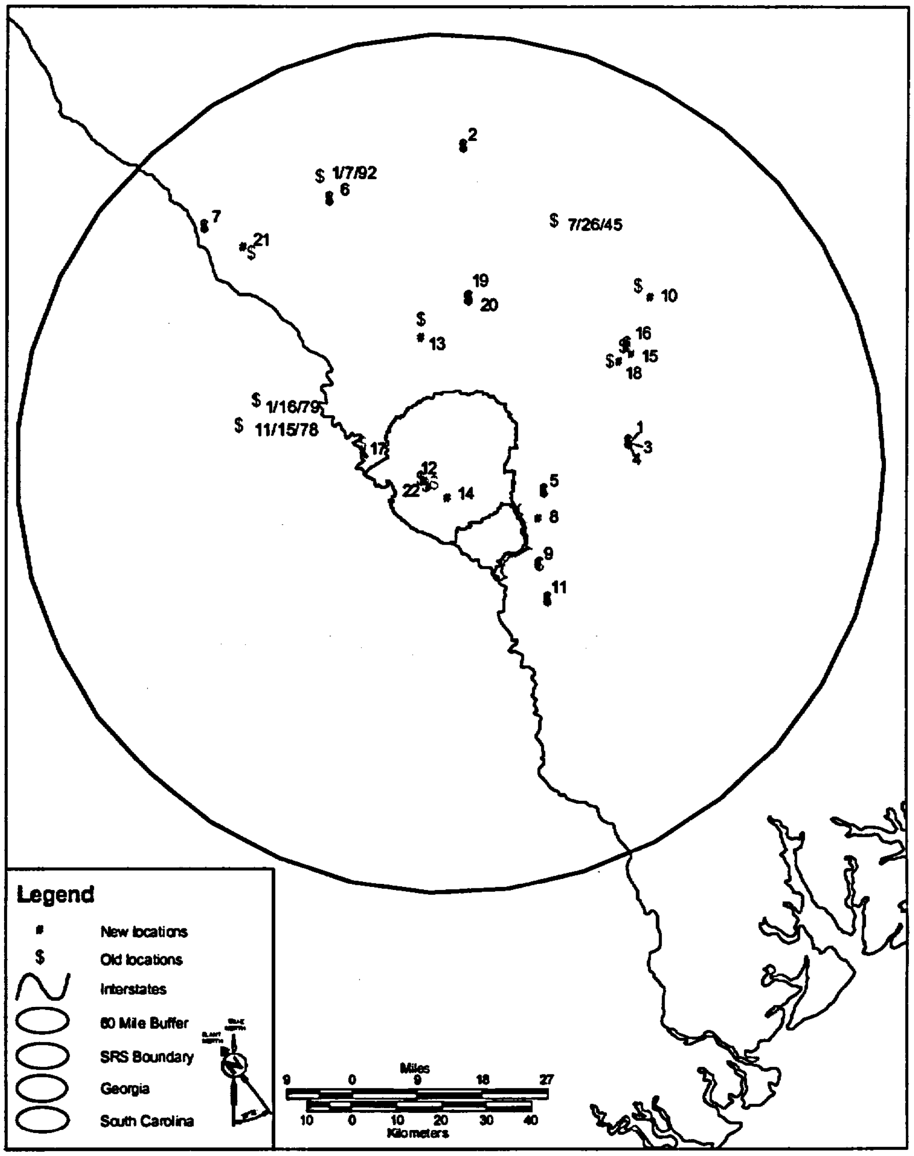

Data from WSRC 2000b

Figure 1.3.6-3. Historical Seismic Events. $ Sign with Date are Historically Mis-located.

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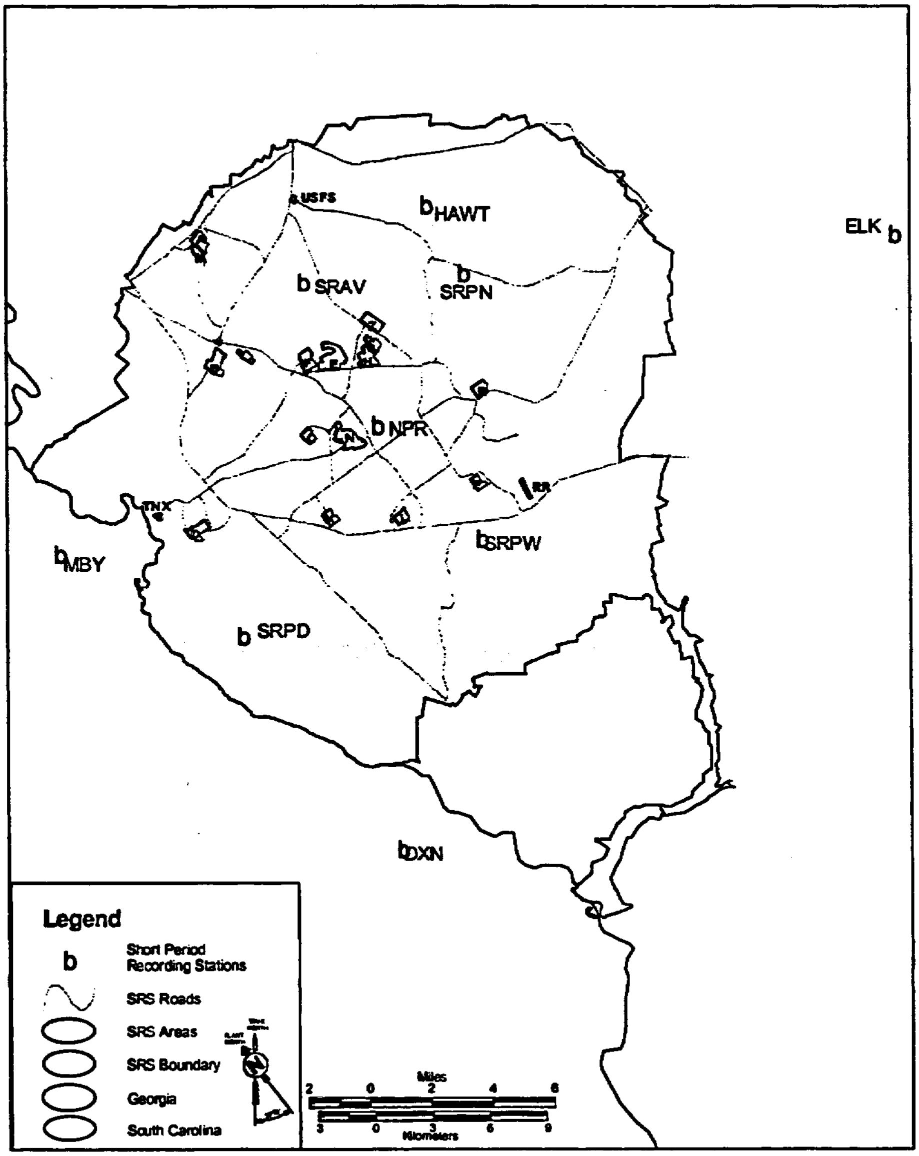

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Figure 1.3.6-4. SRS Short Period Recording Stations

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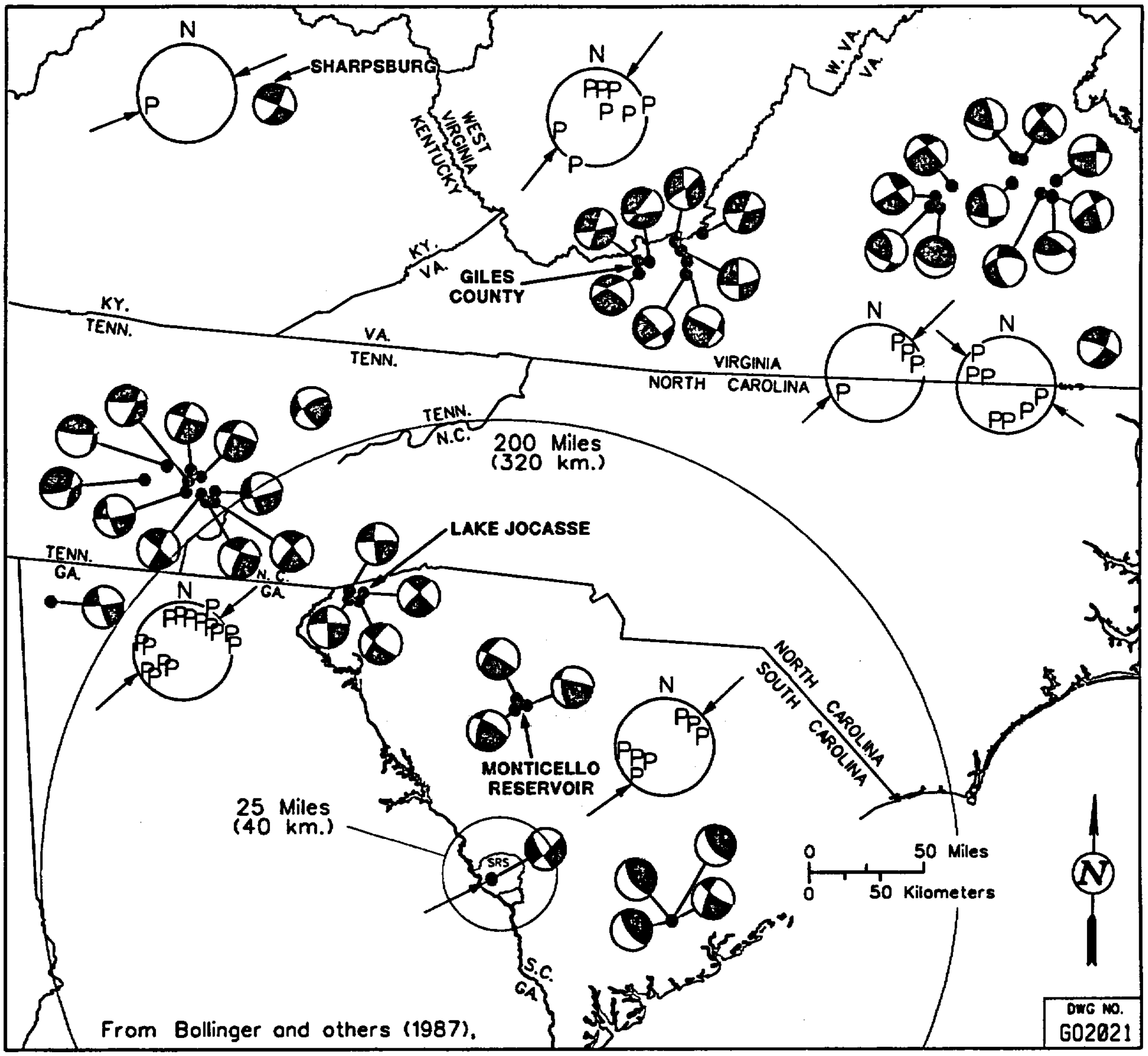

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Figure 1.3.6-5. Summary Fault Plane Solutions for Southeastern United States

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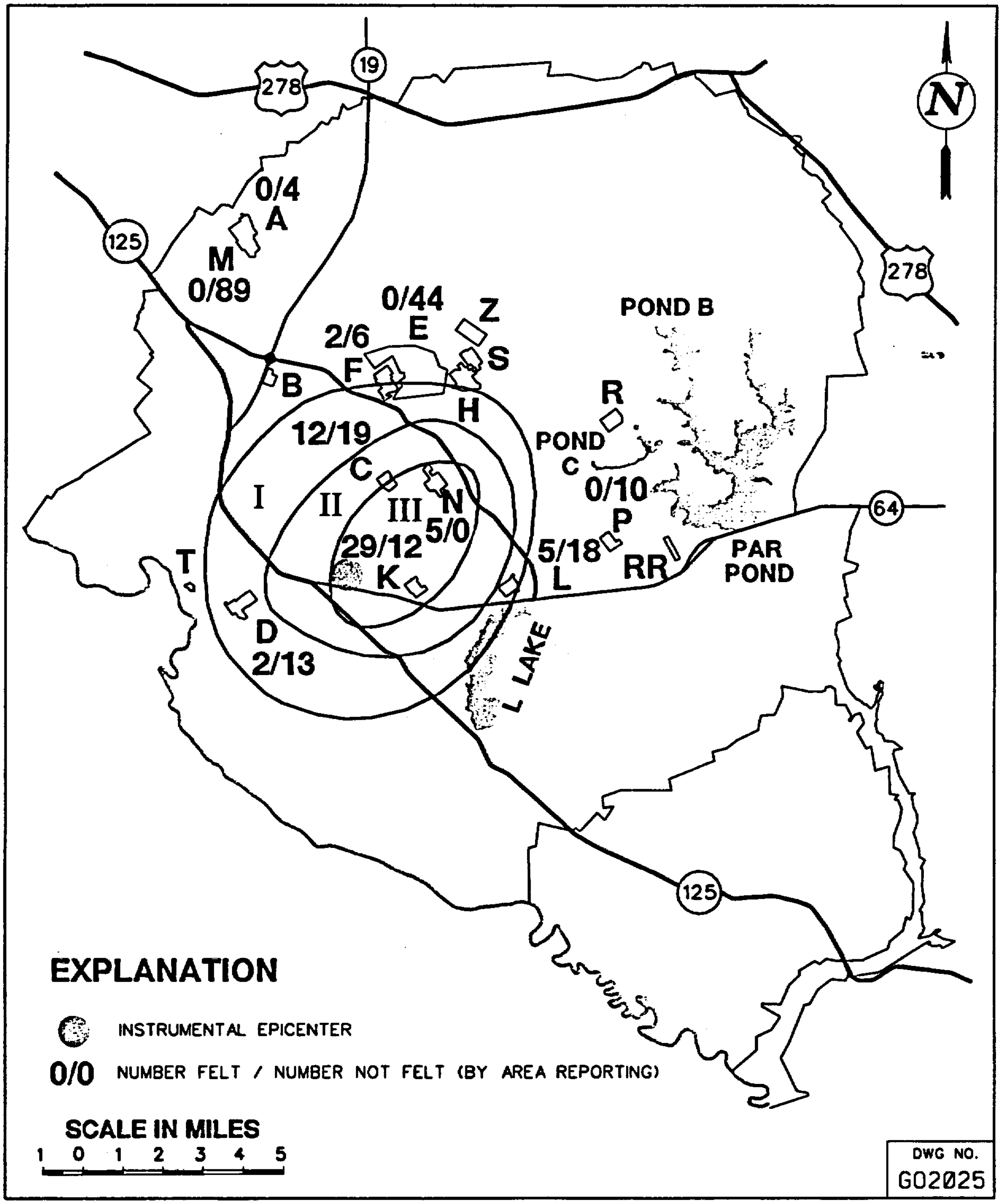

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Figure 1.3.6-6. Isoseismal Map for the June 1985 Earthquake

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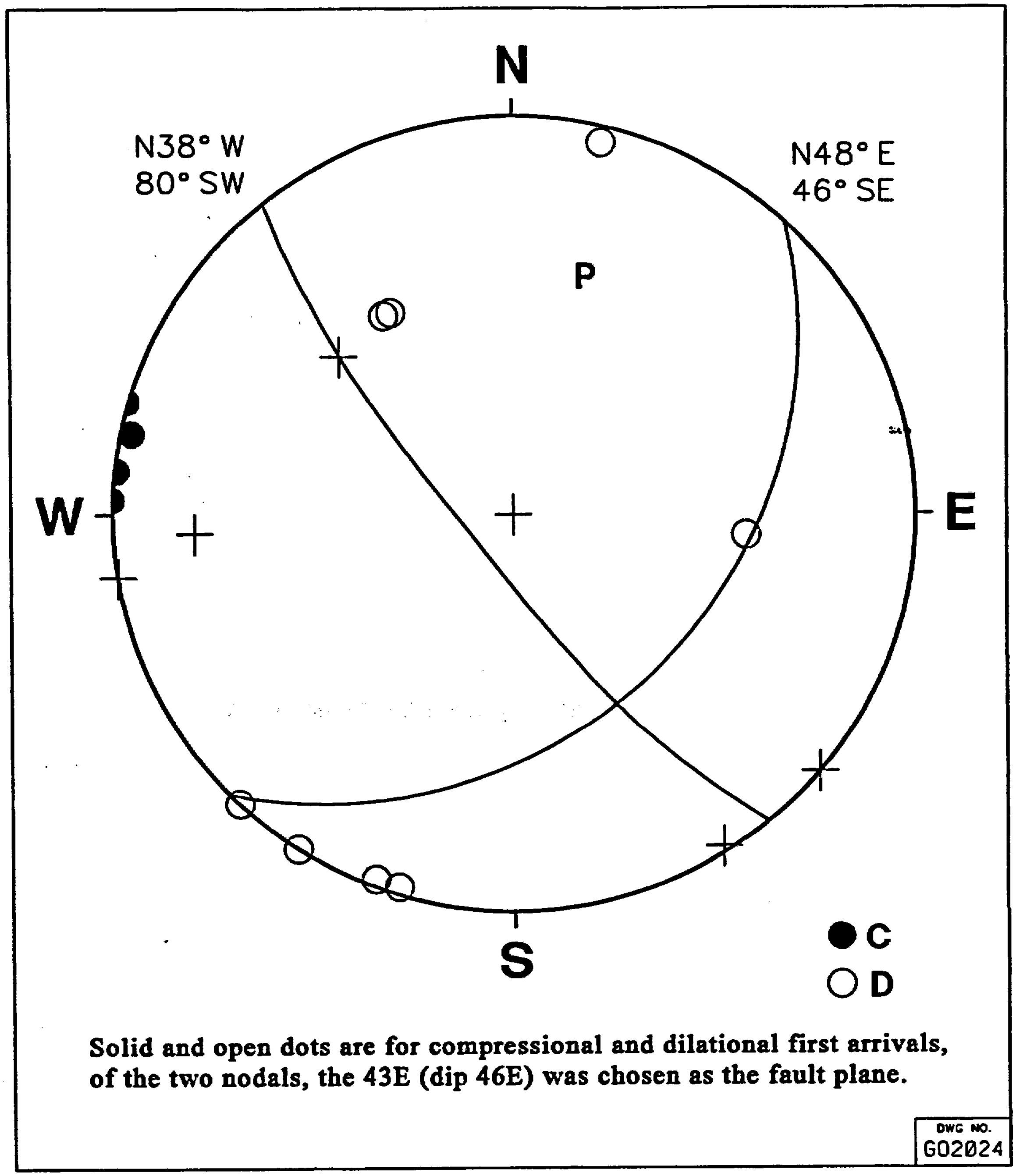

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Figure 1.3.6-7. Fault Plane Solution for the June 1985 Earthquake

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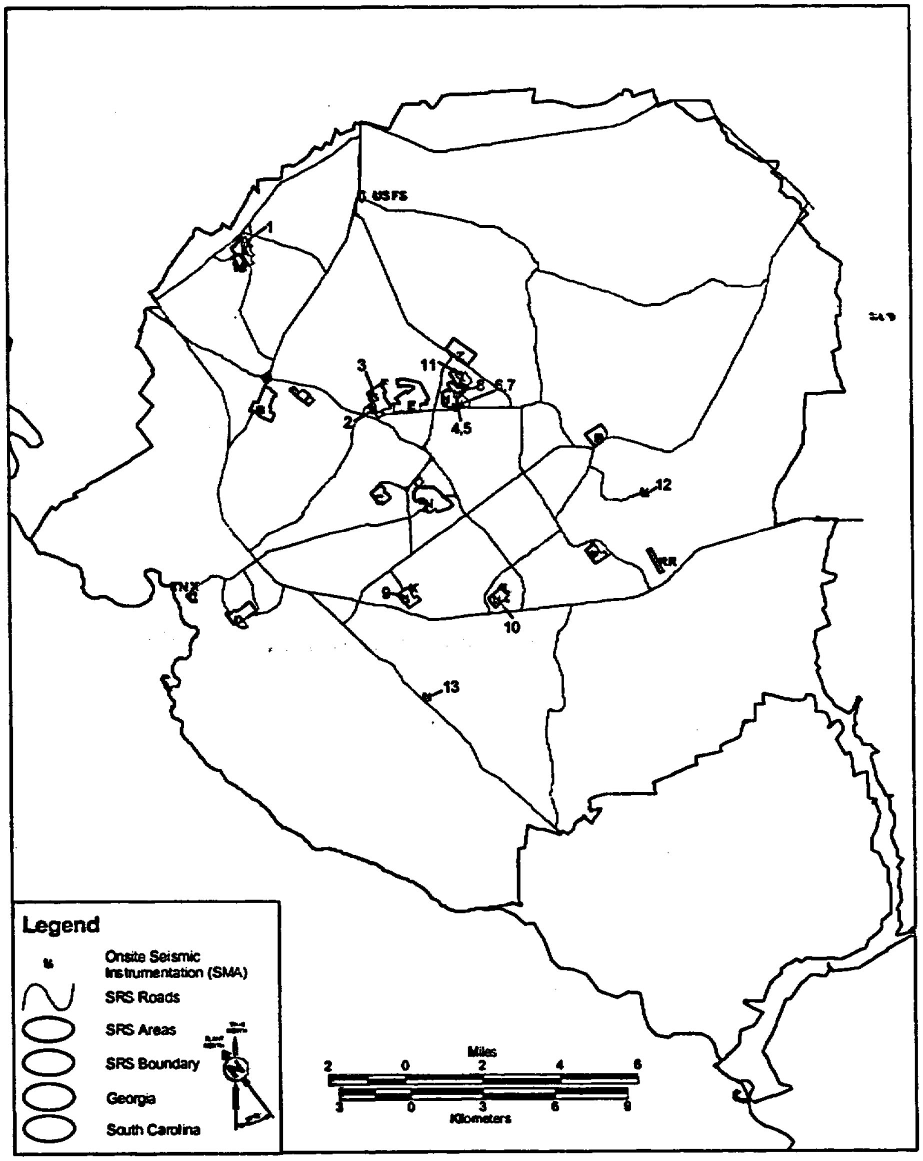

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Figure 1.3.6-8. Location of Strong Motion Accelerographs

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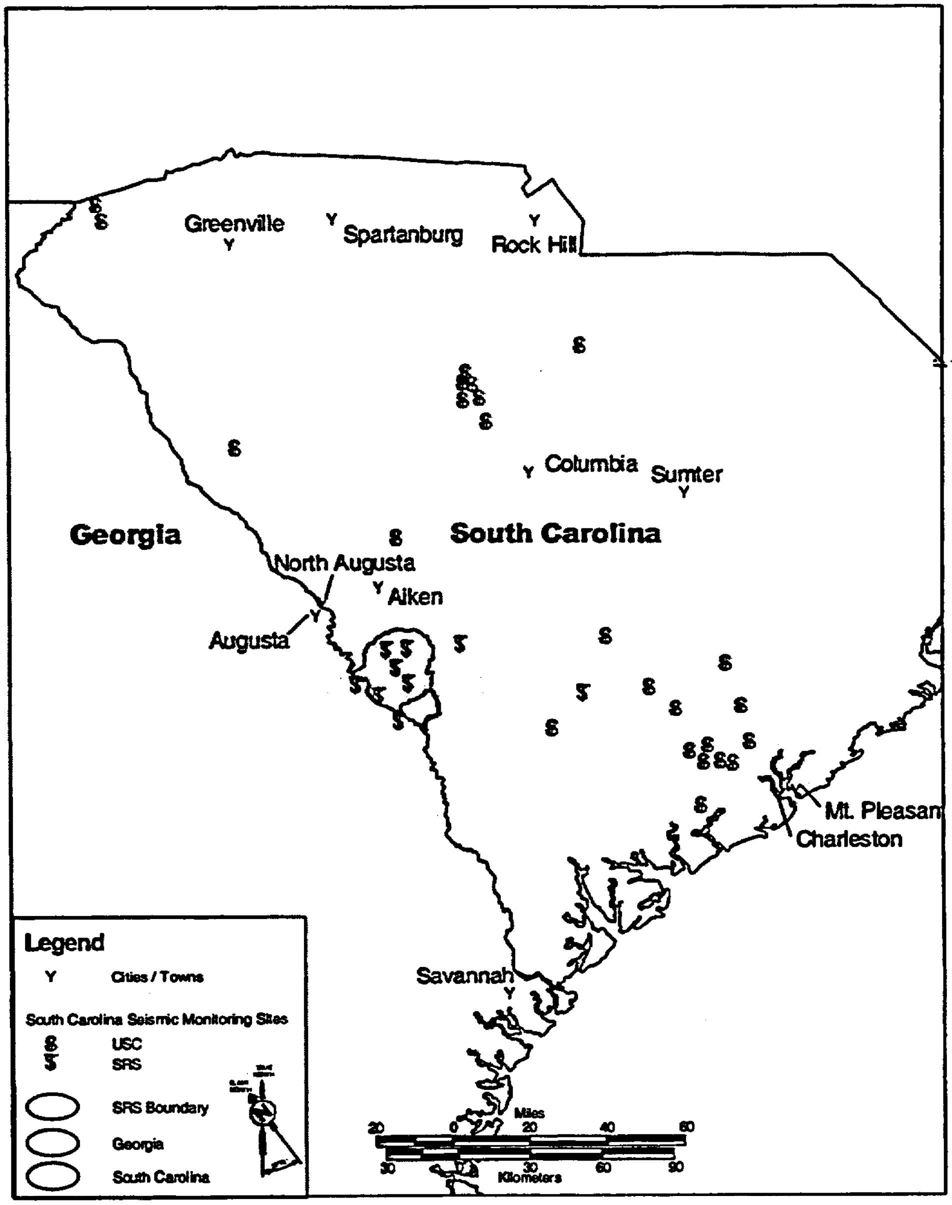

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Figure 1.3.6-9. Seismic Network for SRS and the Surrounding Region

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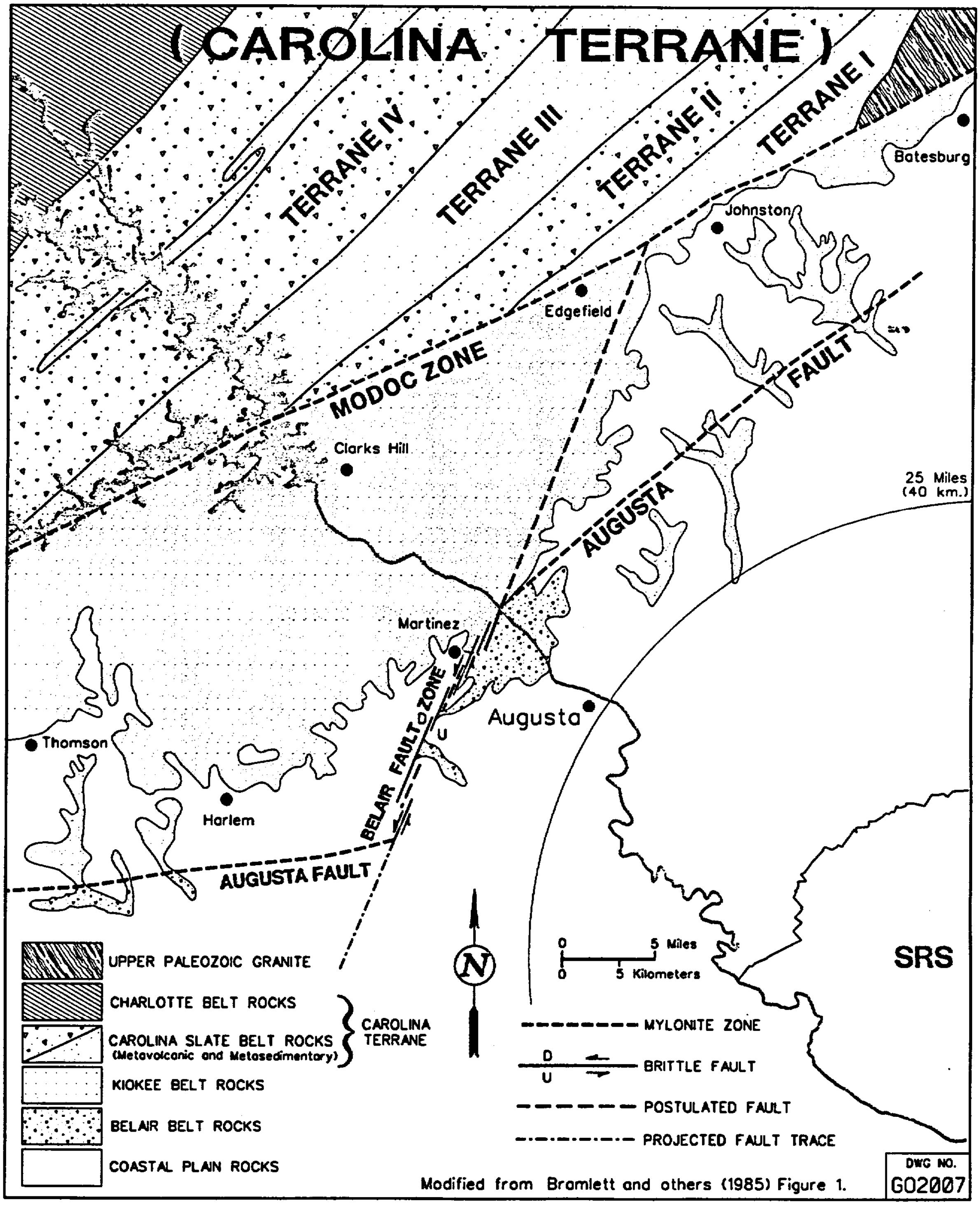

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Figure 1.3.6-10. Carolina Terrane

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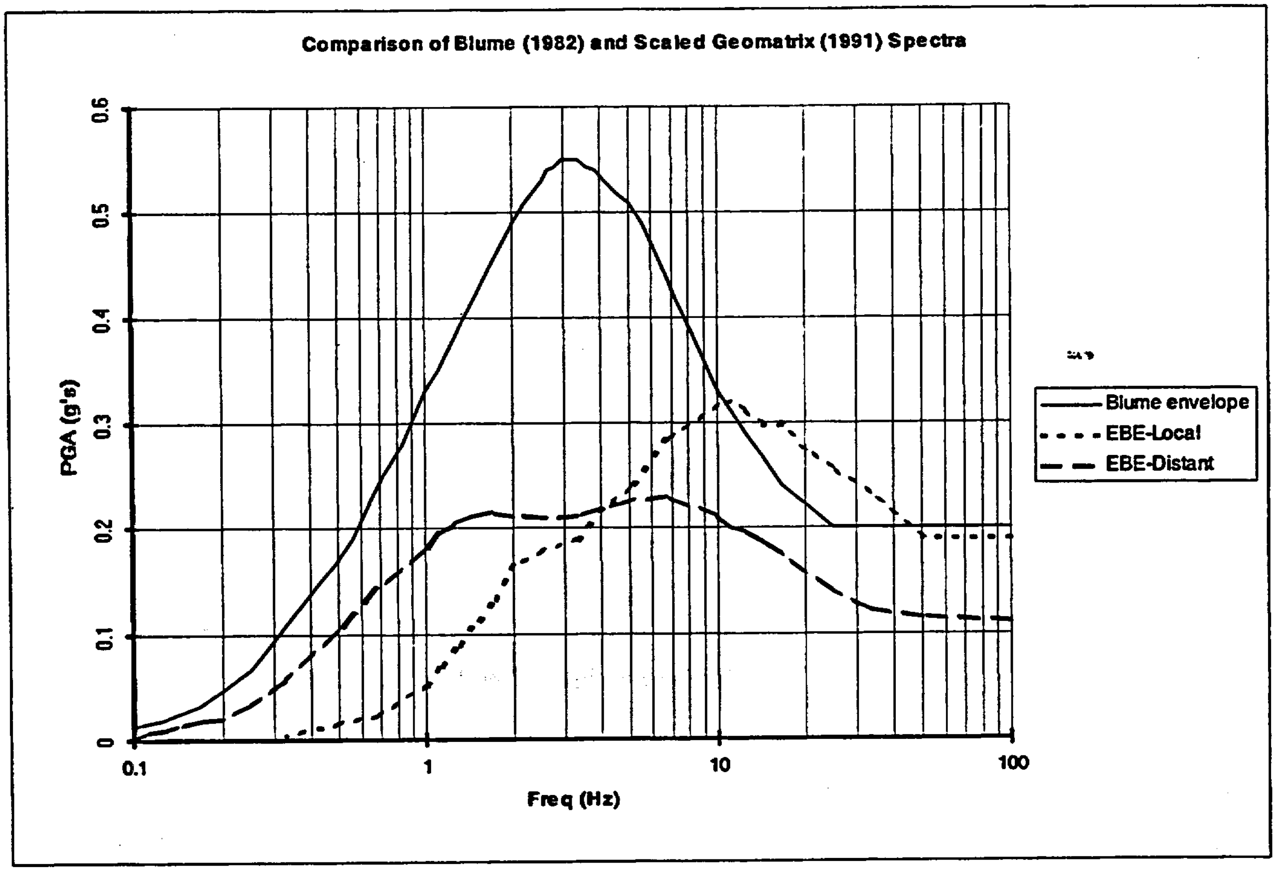

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Figure 1.3.6-11. Response Spectrum Envelope Developed by URS/Blume (1982)

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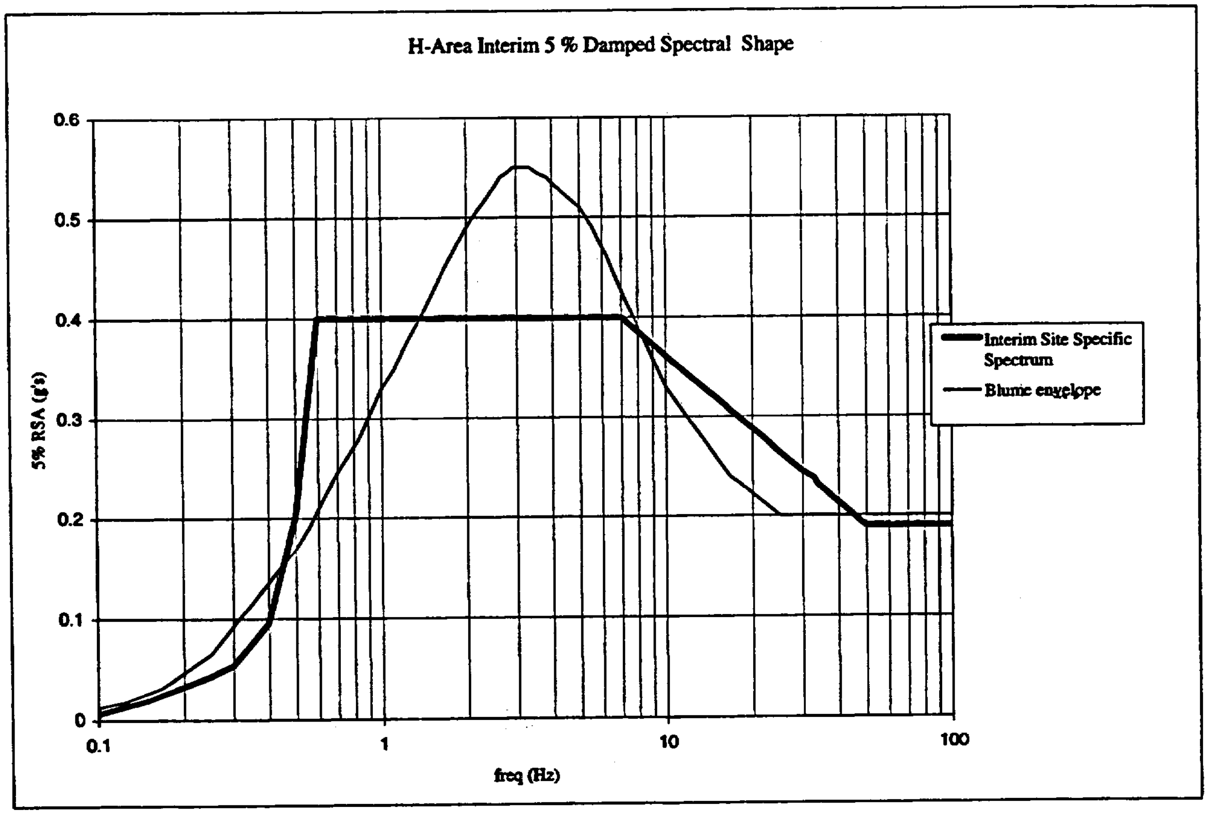

Data from WSRC 2000b

Figure 1.3.6-12. Interim Site Spectrum Versus Blume Envelope

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PC-3 Response Spectra Envelopes

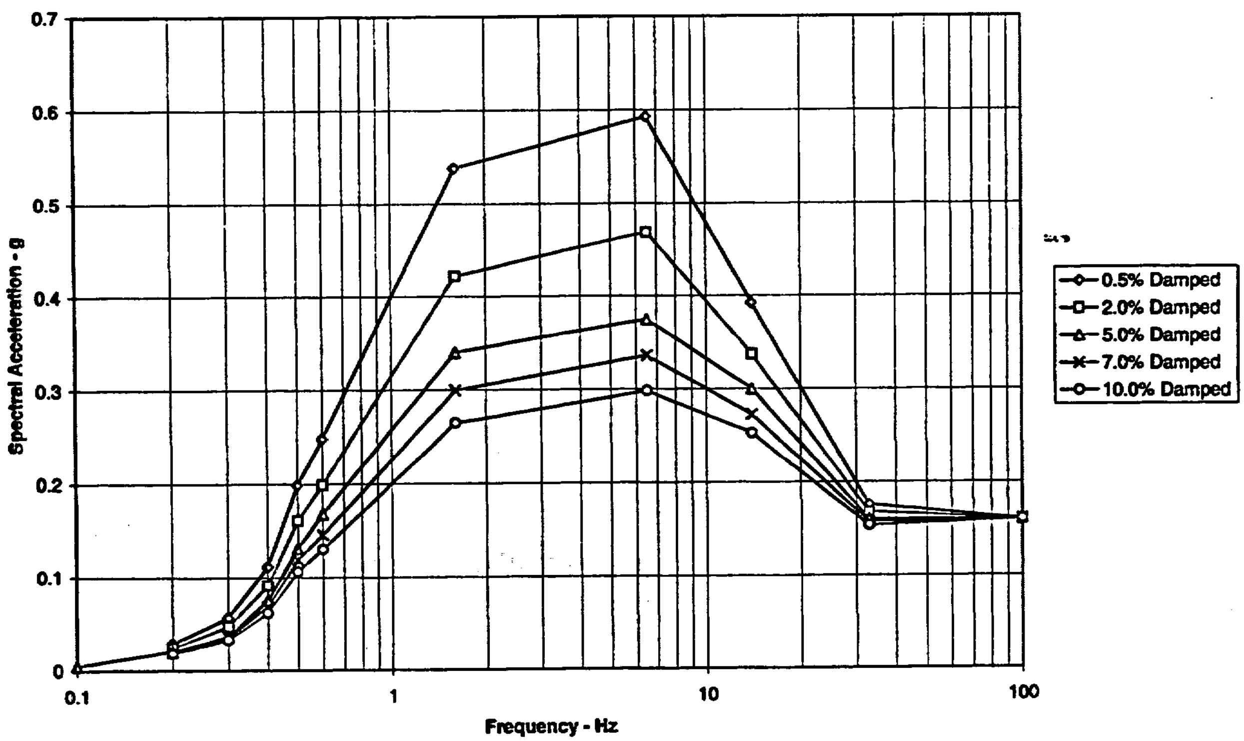

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Figure 1.3.6-13. PC-3 Response Spectra Envelopes

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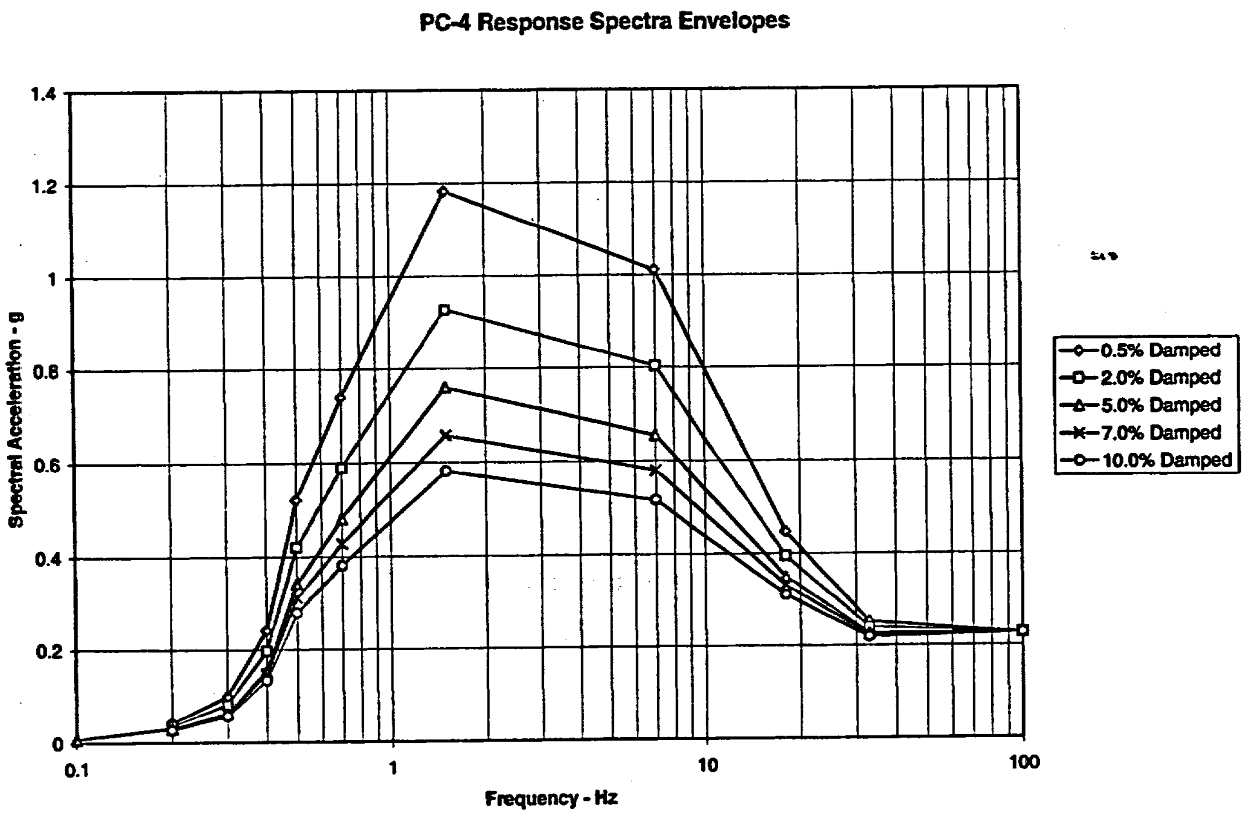

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Figure 1.3.6-14. PC-4 Response Spectra Envelopes

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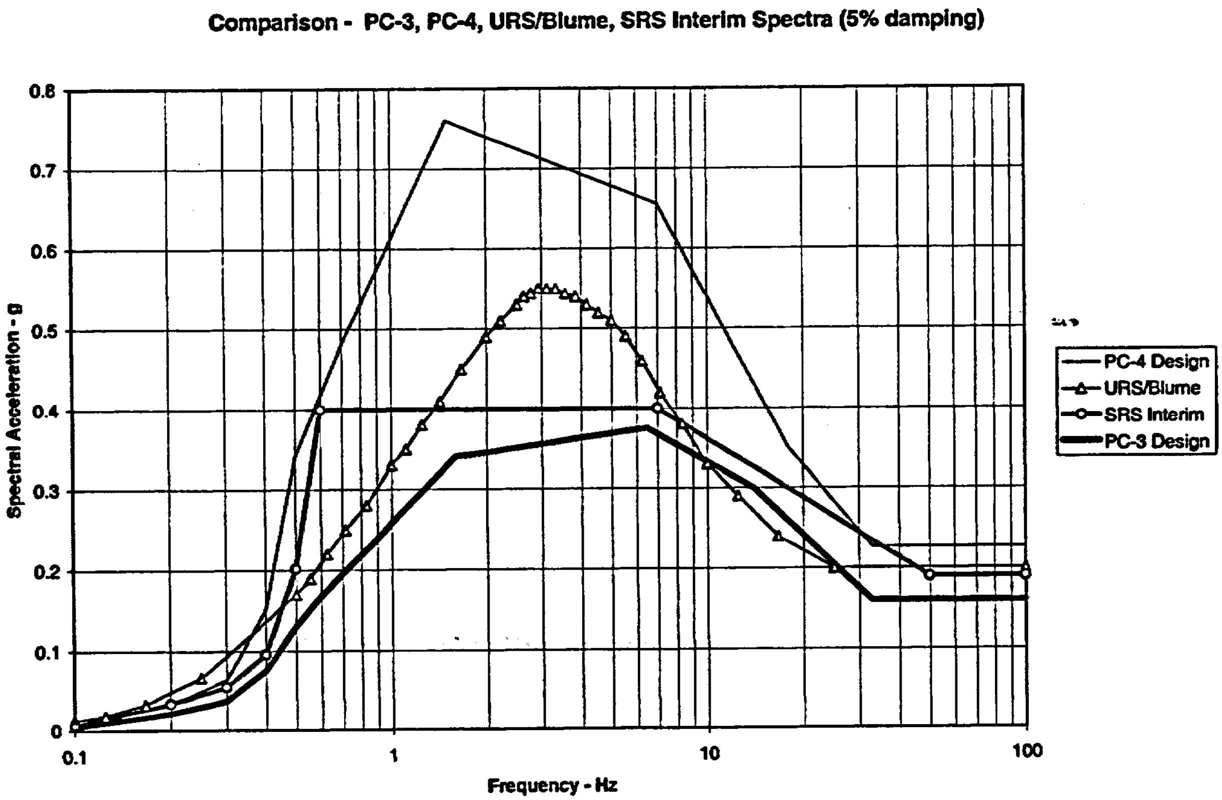

Data from WSRC 2000b

Figure 1.3.6-15. Comparison – PC-3, PC-4, Blume, SRS Interim Spectra (5% Damping)

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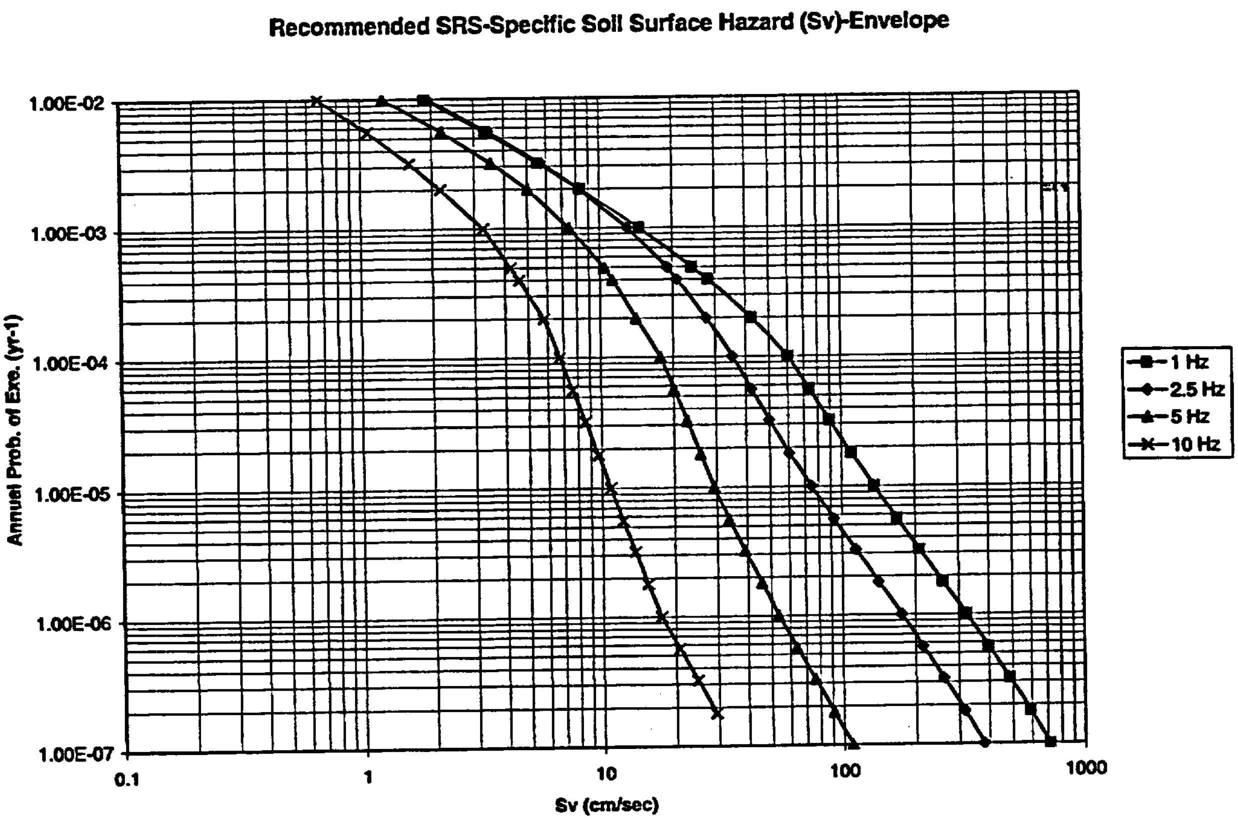

Data from WSRC 2000b

Figure 1.3.6-16. Combined EPRI and LLNL Soil Surface Hazard Envelope (Probability of Exceedence vs 5% Damped Spectral Velocity) for Oscillator Frequencies of 1, 2.5, 5, and 10 Hz.

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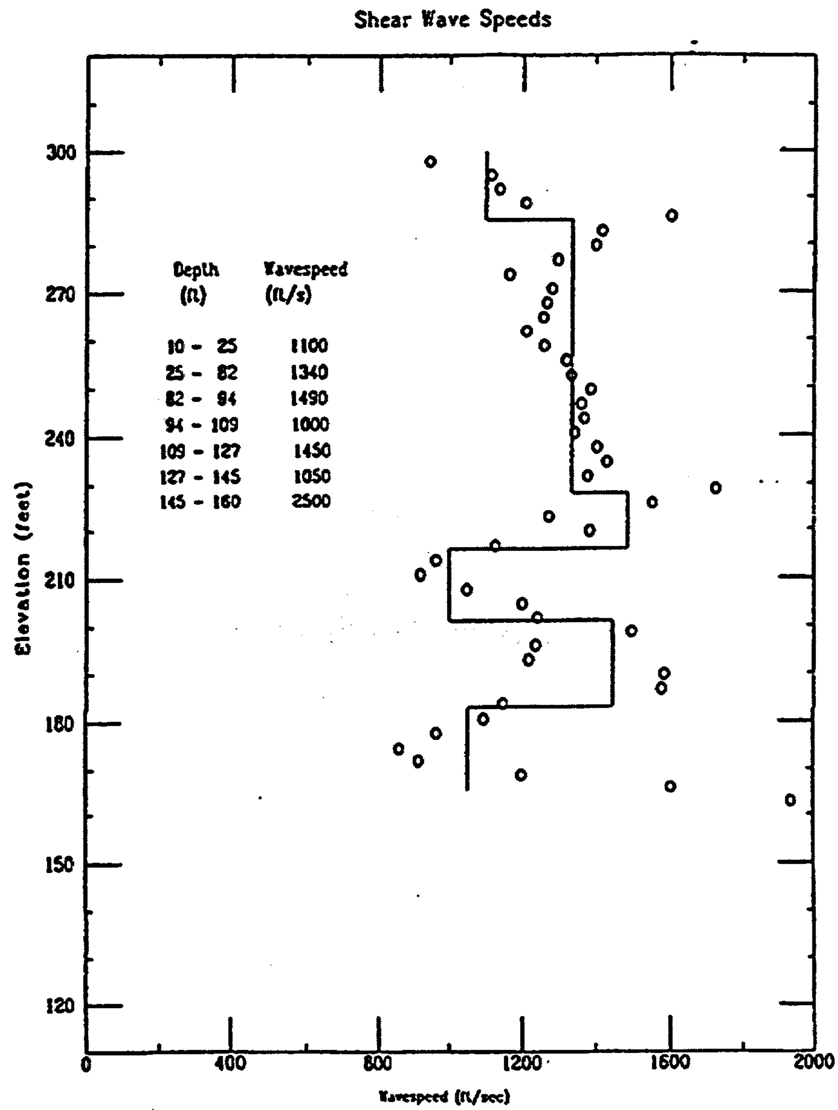

Data from WSRC 2000b

Figure 1.3.6-17. Example Seismic Cone Penetrometer S-Wave Interpretation (Solid Lines) Measurement Taken in F Area

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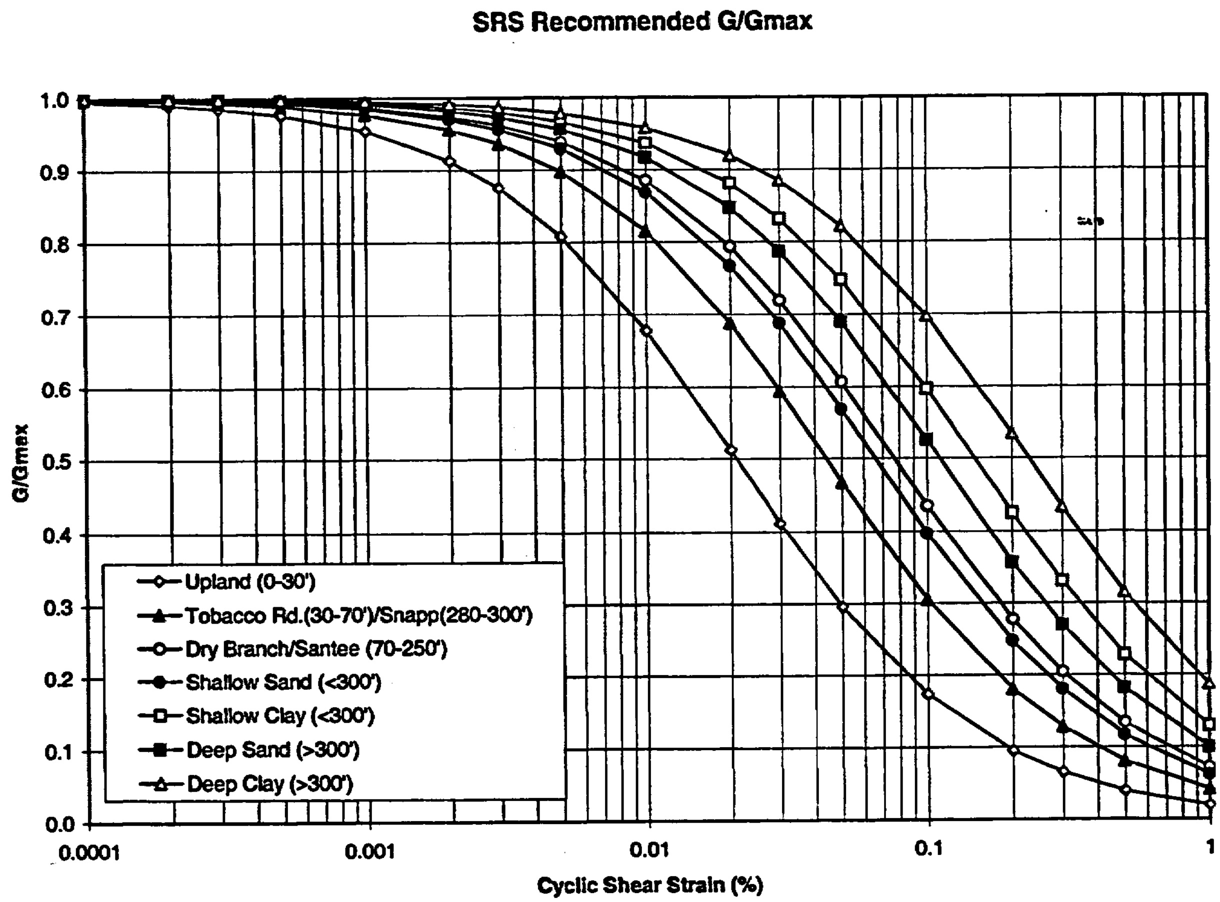

Data from WSRC 2000b

Figure 1.3.6-18. SRS Recommended G/Gmax

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SRS Recommended Damping

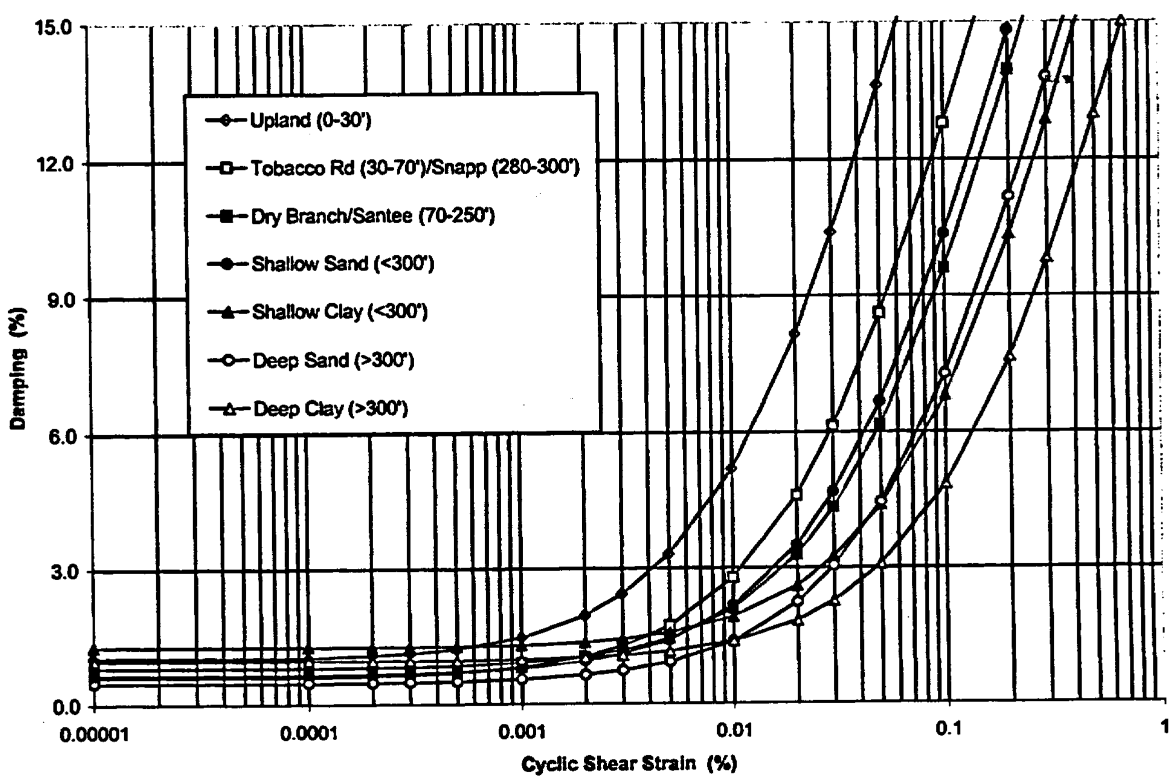

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Figure 1.3.6-19. SRS Recommended Damping

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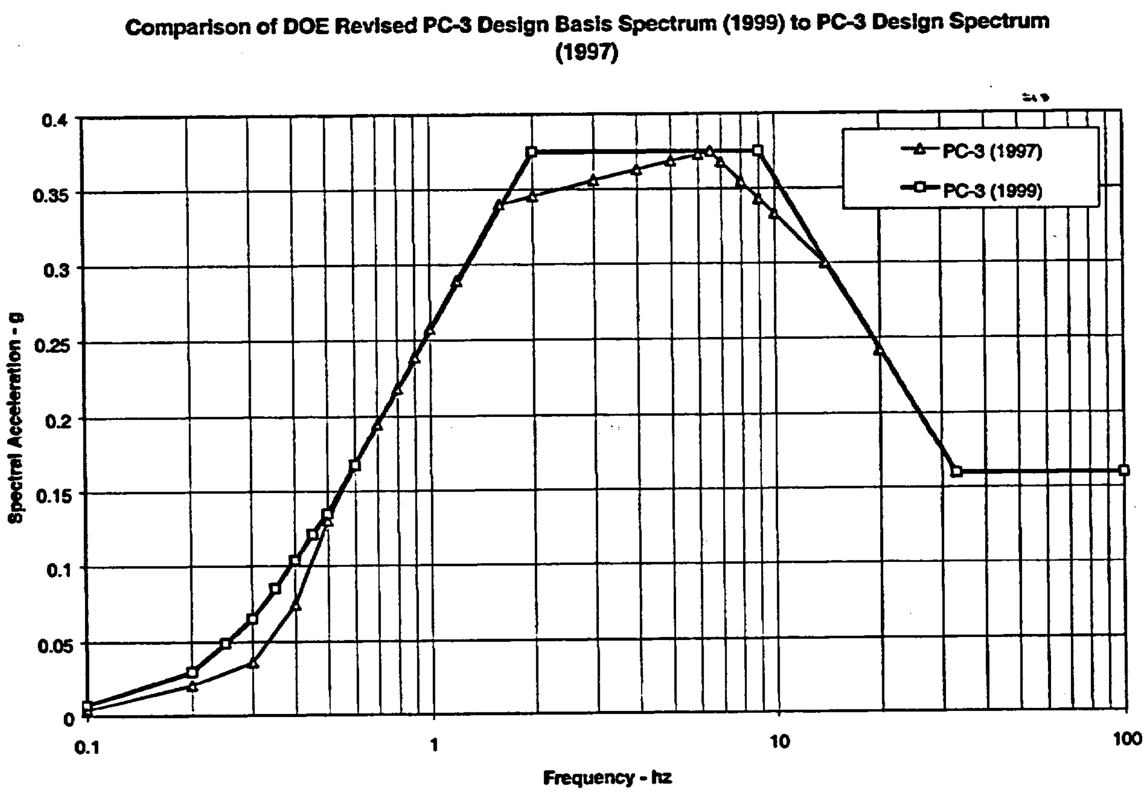

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Figure 1.3.6-20. Revised SRS PC-3 5% Damped Design Response Spectrum

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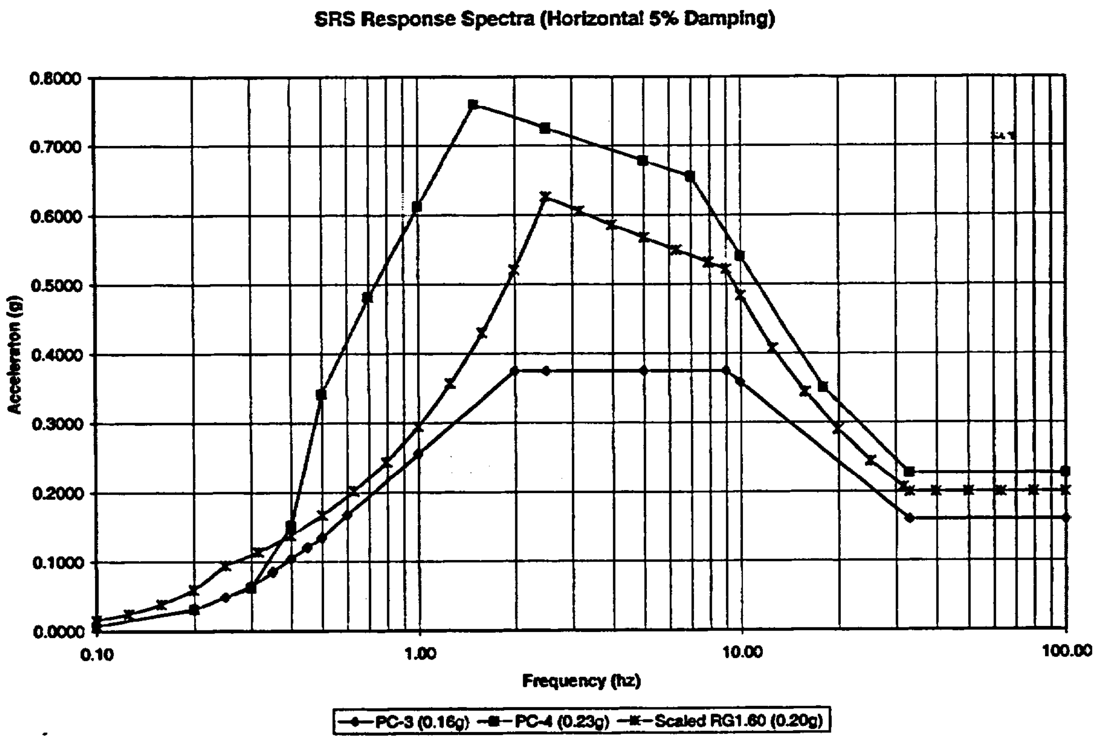

Figure 1.3.6-21. Comparison of 0.2g RG 1.60 Spectrum to PC-3 and PC-4

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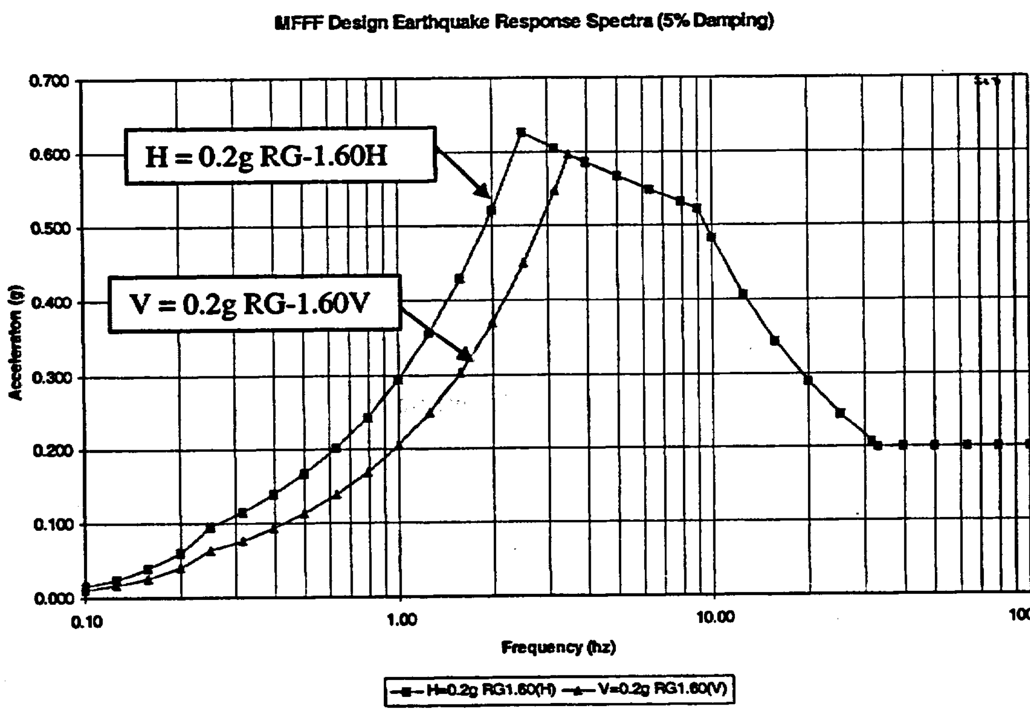

Figure 1.3.6-22. Design Earthquake for MFFF Systems, Structures, and Equipment

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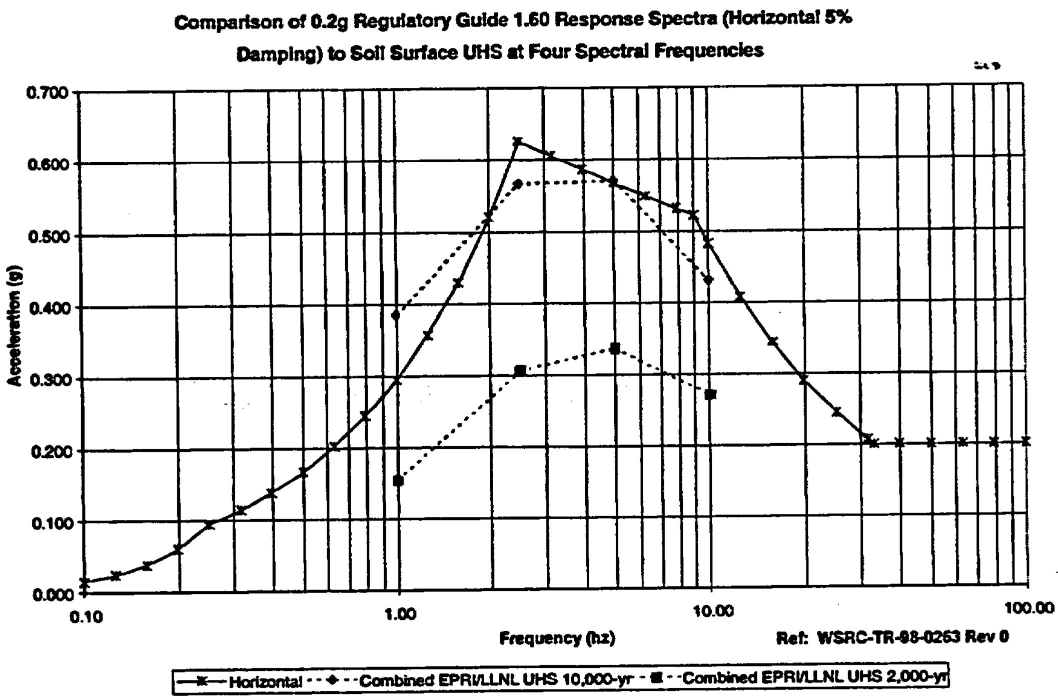

Data from WSRC 1998

Figure 1.3.6-23. Comparison of 0.2g Regulatory Guide 1.60 Response Spectra (Horizontal 5% Damping) to Soil Surface UHS at Four Spectral Frequencies

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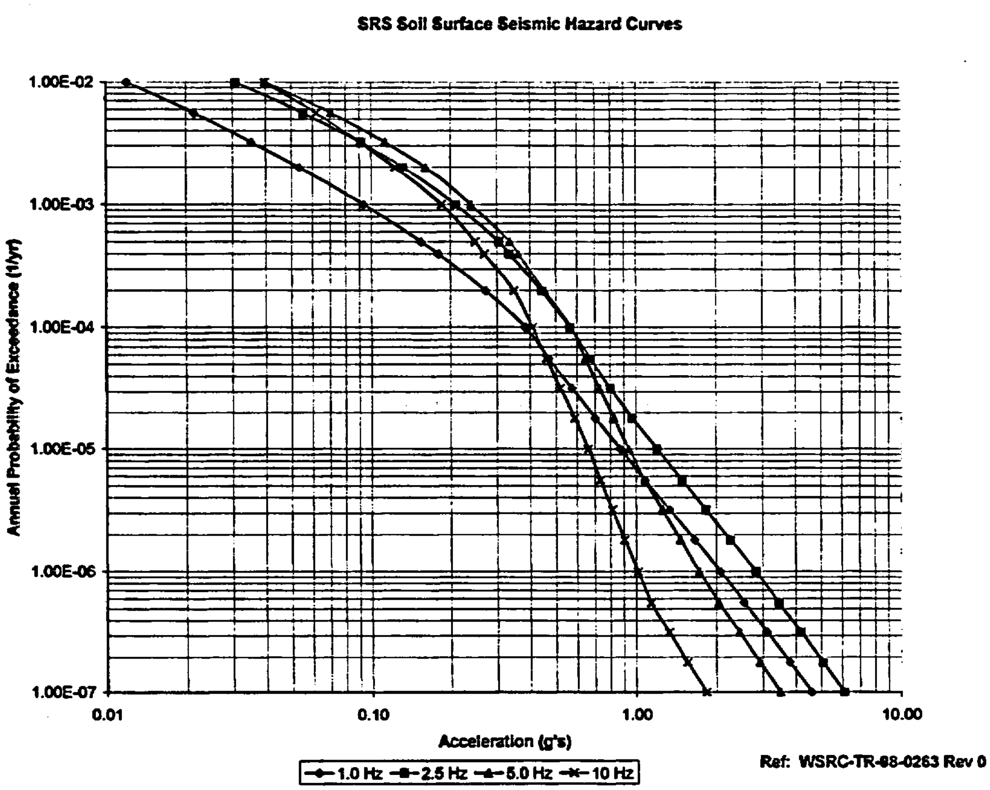

Data from WSRC 1998

Figure 1.3.6-24. SRS Soil Surface Seismic Hazard Curves

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